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Madsen et al.

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(54) **CONTEXT SENSITIVE RELATIONAL FEATURE/MEASUREMENT COMMAND MENU DISPLAY IN COORDINATE MEASUREMENT MACHINE (CMM) USER INTERFACE**

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(51) **Int. Cl.**
G05B 19/401 (2006.01)
G01B 21/04 (2006.01)

(52) **U.S. Cl.**
CPC ***G05B 19/401*** (2013.01); ***G01B 21/047*** (2013.01); *G05B 2219/37443* (2013.01); *G05B 2219/37453* (2013.01)

(58) **Field of Classification Search**
CPC G05B 19/401; G05B 2219/37443; G05B 2219/37453; G01B 21/047
See application file for complete search history.

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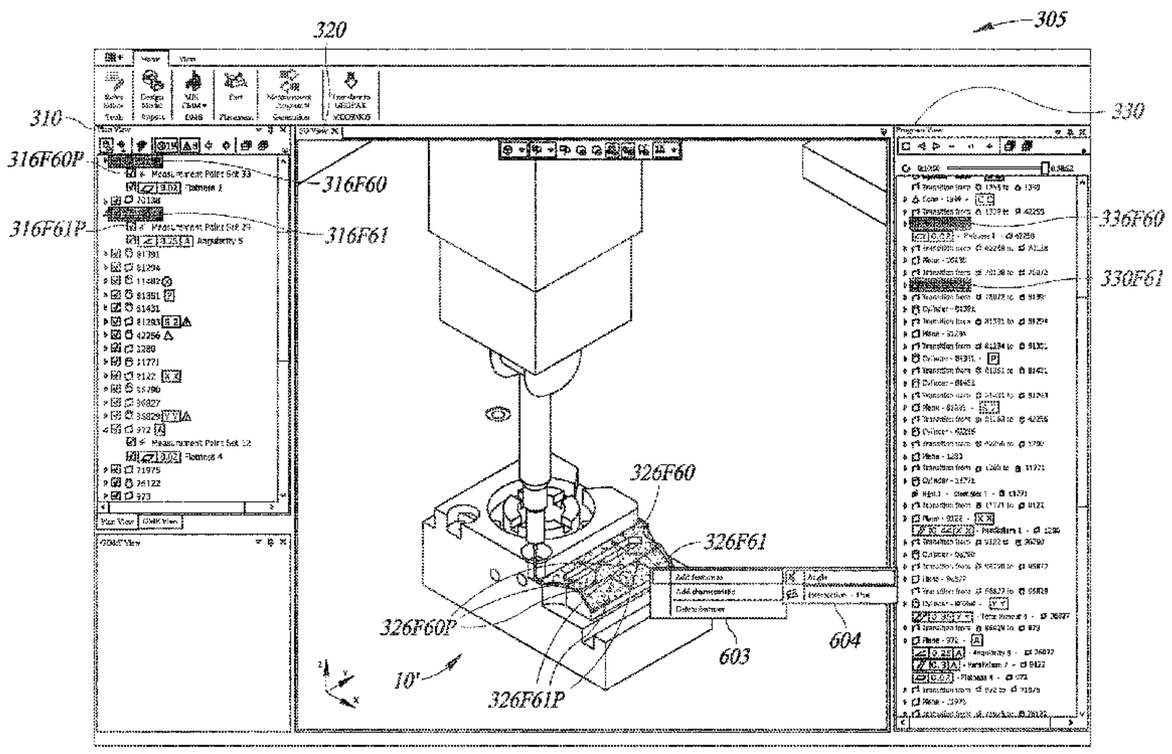
(57) **ABSTRACT**

A system is provided for programming workpiece feature inspection operations for a coordinate measuring machine. The system includes a computer-aided design (CAD) file processing portion, a geometric relationship analyzer, an inspection motion path generation portion, and a user interface including an editable plan representation of a current workpiece feature inspection plan, a workpiece inspection program simulation portion configured to display a 3D view including geometric features and inspection operation representations, and a context sensitive menu portion. The context sensitive menu portion displays a context sensitive relational command menu that indicates a valid set of relational commands including relational feature or relational measurement commands operable to define a corresponding constructed feature or corresponding relational measurement operation to be included in the current workpiece feature inspection plan. The valid set of relational commands is determined based on a concurrently selected geometric feature set including at least two geometric features concurrently selected and indicated in the user interface.

25 Claims, 14 Drawing Sheets



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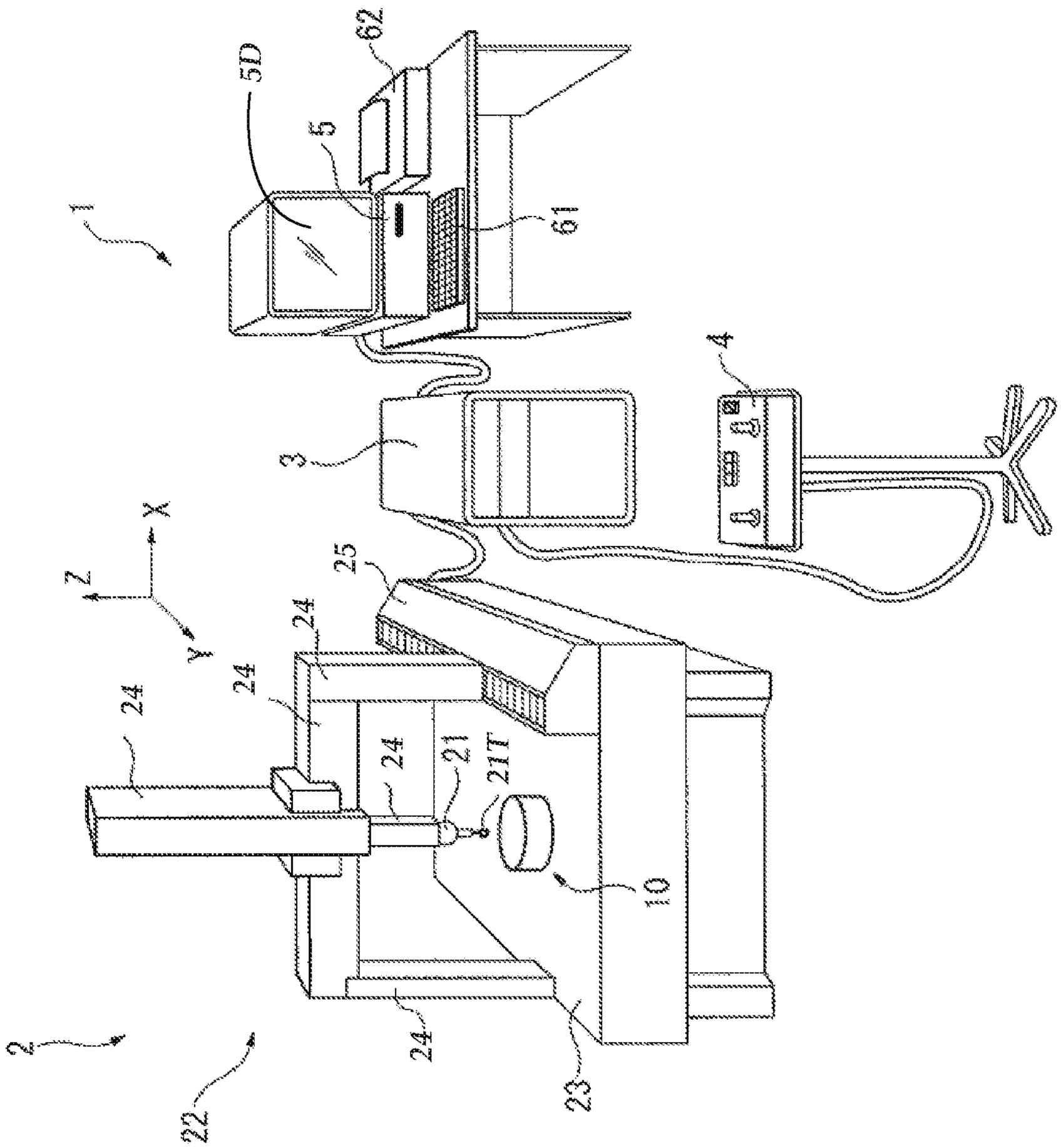

Fig. 1

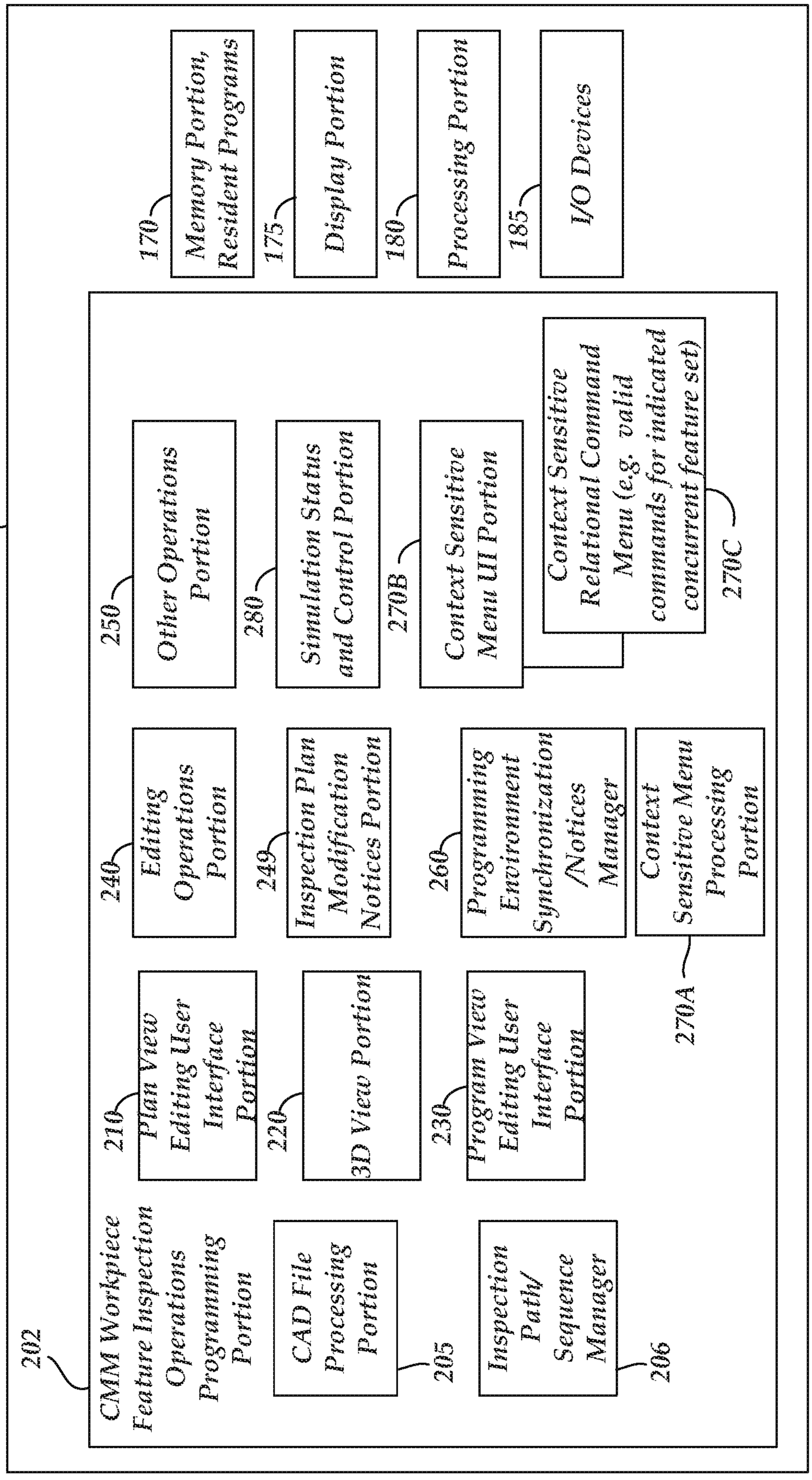
105
170
Memory Portion, Resident Programs
175
Display Portion
180
Processing Portion
185
I/O Devices
250
Other Operations Portion
280
Simulation Status and Control Portion
270B
Context Sensitive Menu UI Portion
Context Sensitive Relational Command Menu (e.g. valid commands for indicated concurrent feature set)
270C
240
Editing Operations Portion
249
Inspection Plan Modification Notices Portion
260
Programming Environment Synchronization /Notices Manager
Context Sensitive Menu Processing Portion
270A
202
CMM Workpiece Feature Inspection Operations Programming Portion
210
Plan View Editing User Interface Portion
220
3D View Portion
230
Program View Editing User Interface Portion
CAD File Processing Portion
205
Inspection Path/ Sequence Manager
206

Fig. 2A

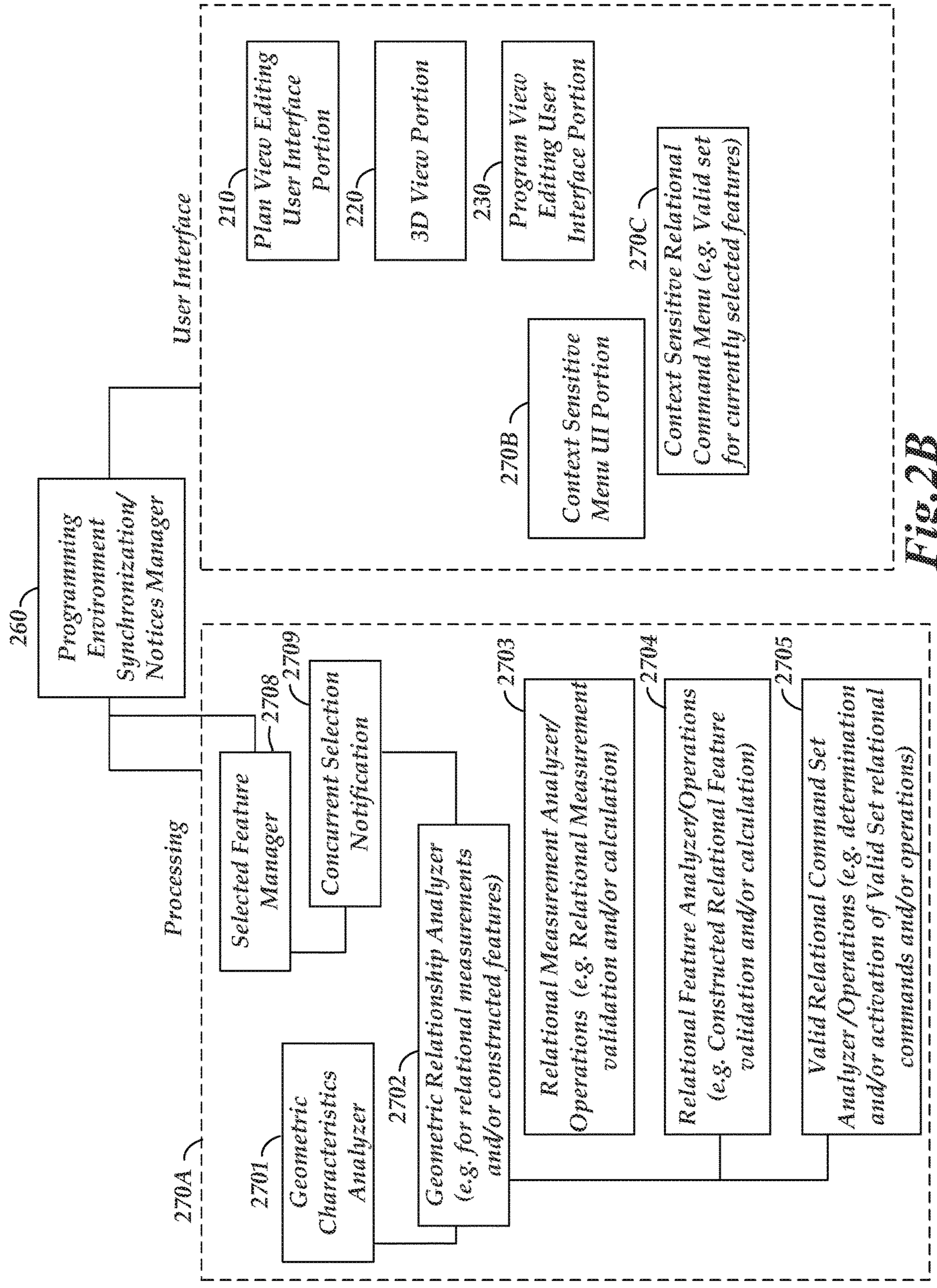
User Interface
210
Plan View Editing User Interface Portion
220
3D View Portion
230
Program View Editing User Interface Portion
270C
Context Sensitive Relational Command Menu (e.g. Valid set for currently selected features)
270B
Context Sensitive Menu UI Portion
260
Programming Environment Synchronization/ Notices Manager
Processing
2708
Selected Feature Manager
2709
Concurrent Selection Notification
2703
Relational Measurement Analyzer/ Operations (e.g. Relational Measurement and/or calculation)
2704
Relational Feature Analyzer/Operations (e.g. Constructed Relational Feature validation and/or calculation)
2705
Valid Relational Command Set Analyzer/Operations (e.g. determination of Valid Set relational commands and/or operations)
270A
2701
Geometric Characteristics Analyzer
2702
Geometric Relationship Analyzer (e.g. for relational measurement and/or constructed features)

Fig. 2B

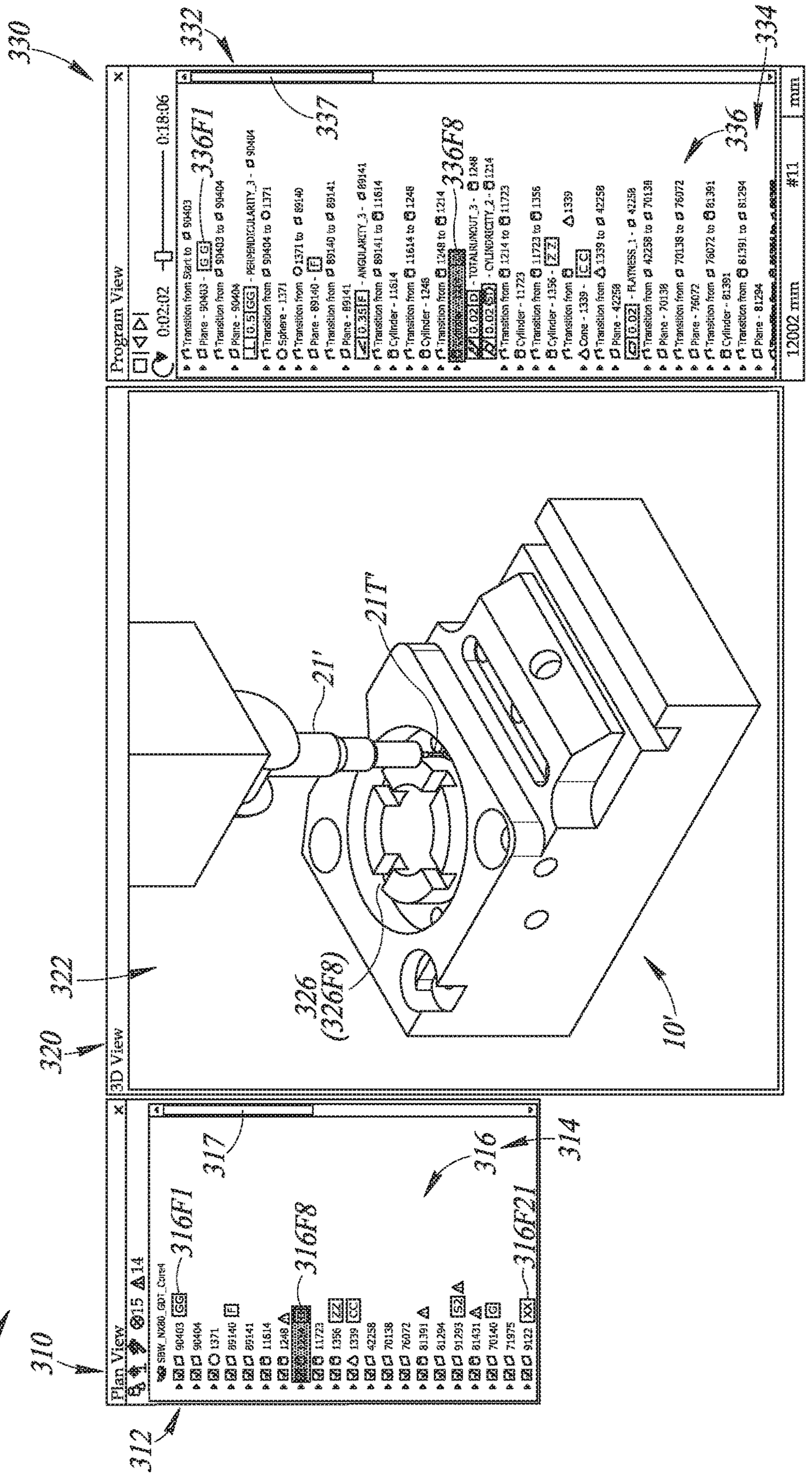
305
310
312
314
316
316F1
316F8
316F21
317
320
322
326
(326F8)
330
332
334
336
336F1
336F8
337
10'
21'
21T'
Program View
Plan View
3D View
12002 mm
#11
mm
0:02:02
0:18:06

FIG. 3

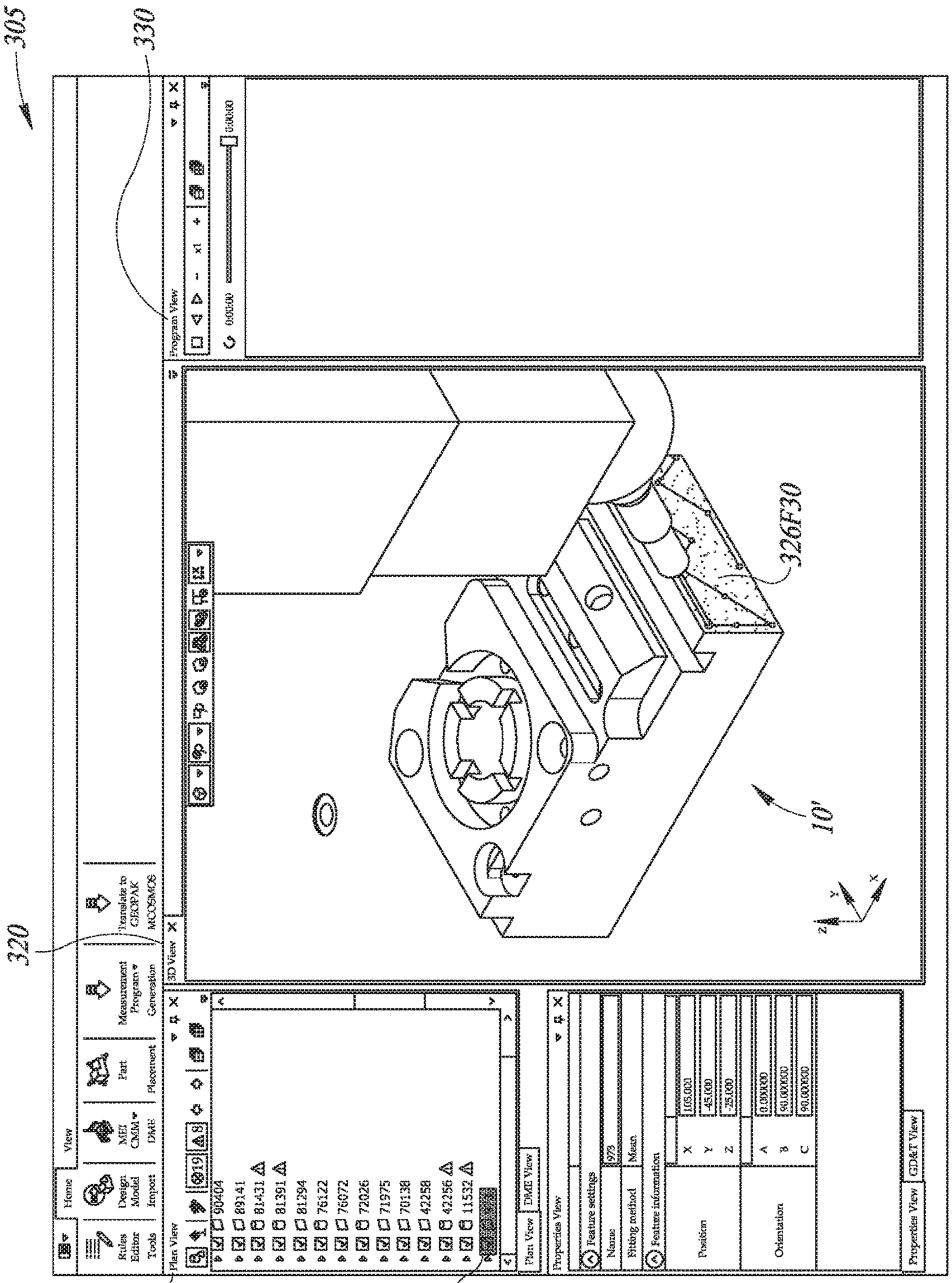
305
330
320
310
316F30
326F30
10'
Program View
Translate to GEOPAK
MCOSMOS
3D View
Plan View
Part View
DME View
Properties View
Feature settings
Feature information
Position
Orientation
GD&T View

FIG. 4

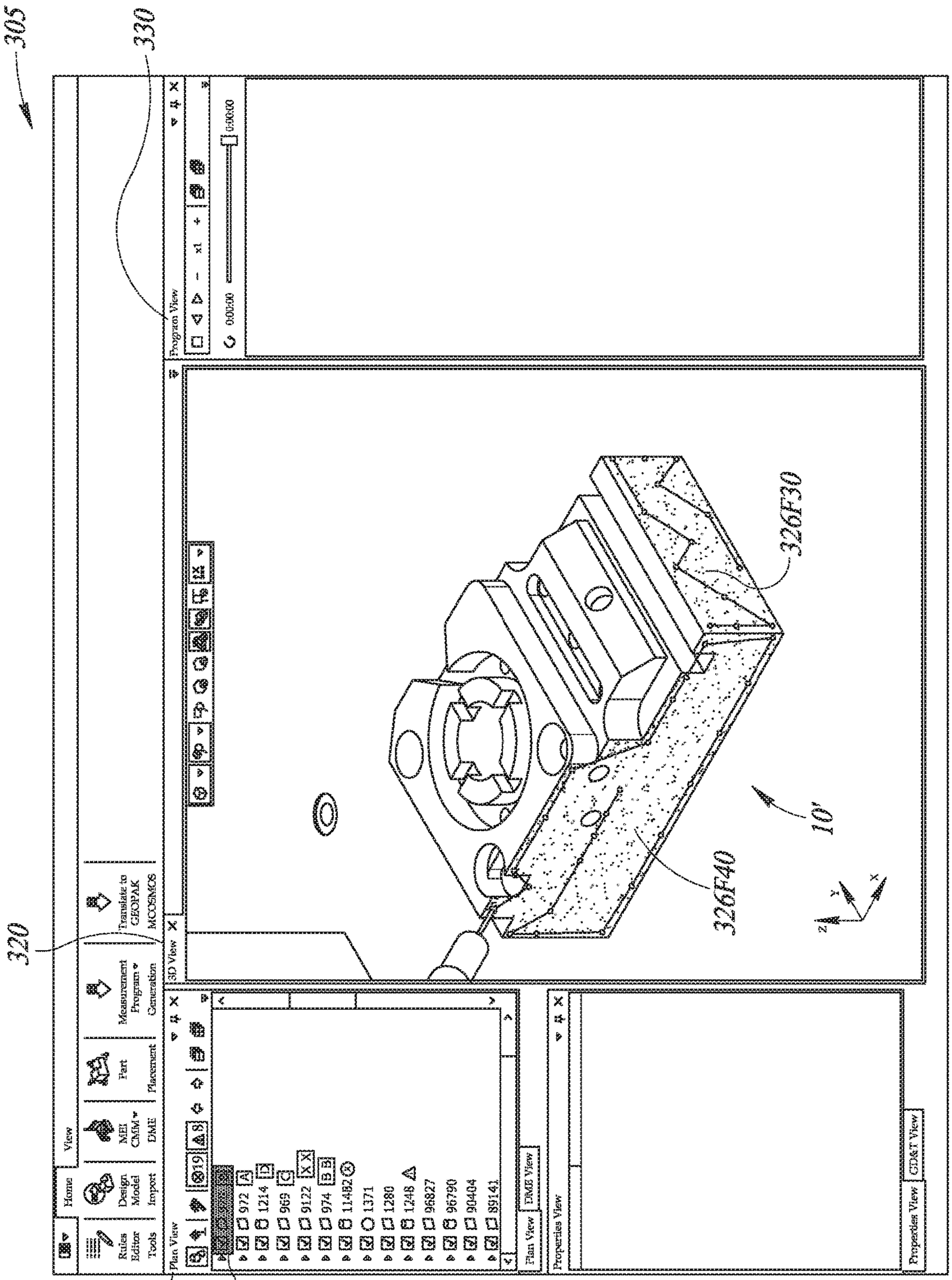
305
330
320
310
316F40
326F30
326F40
10'
Home
View
Rules Editor
Design Model
Import
MBI
CMM
DME
Part
Placement
Measurement Program
Generation
Tools
Translate to GEOPAK
MCOSMOS
Program View
Plan View
3D View
DME View
Properties View
GD&T View

FIG. 5

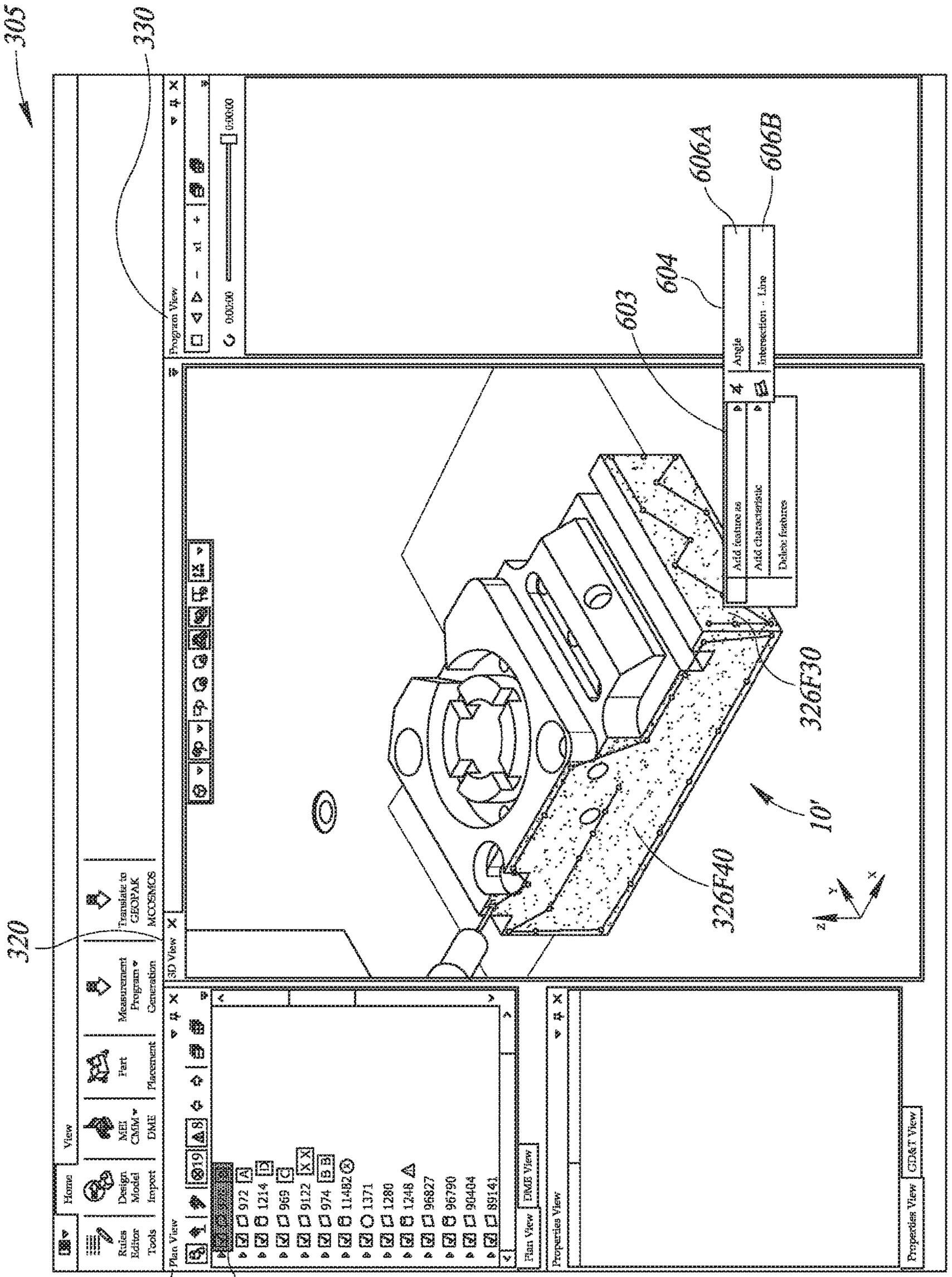
305
330
320
310
316F40
326F30
326F40
10'
603
604
606A
606B
Program View
Translate to GEOPAK
MOSMOS
Rules Editor
Design Model
Import
Tools
MEI
CMM
DME
Part
Placement
Measurement Program
Generation
Home
View
Plan View
3D View
DME View
Properties View
GD&T View
Angle
Intersection - Line
Add feature as
Add characteristic
Delete features
972
1214
969
9122
974
11482
1371
1280
1248
96827
96790
90404
89141

FIG. 6

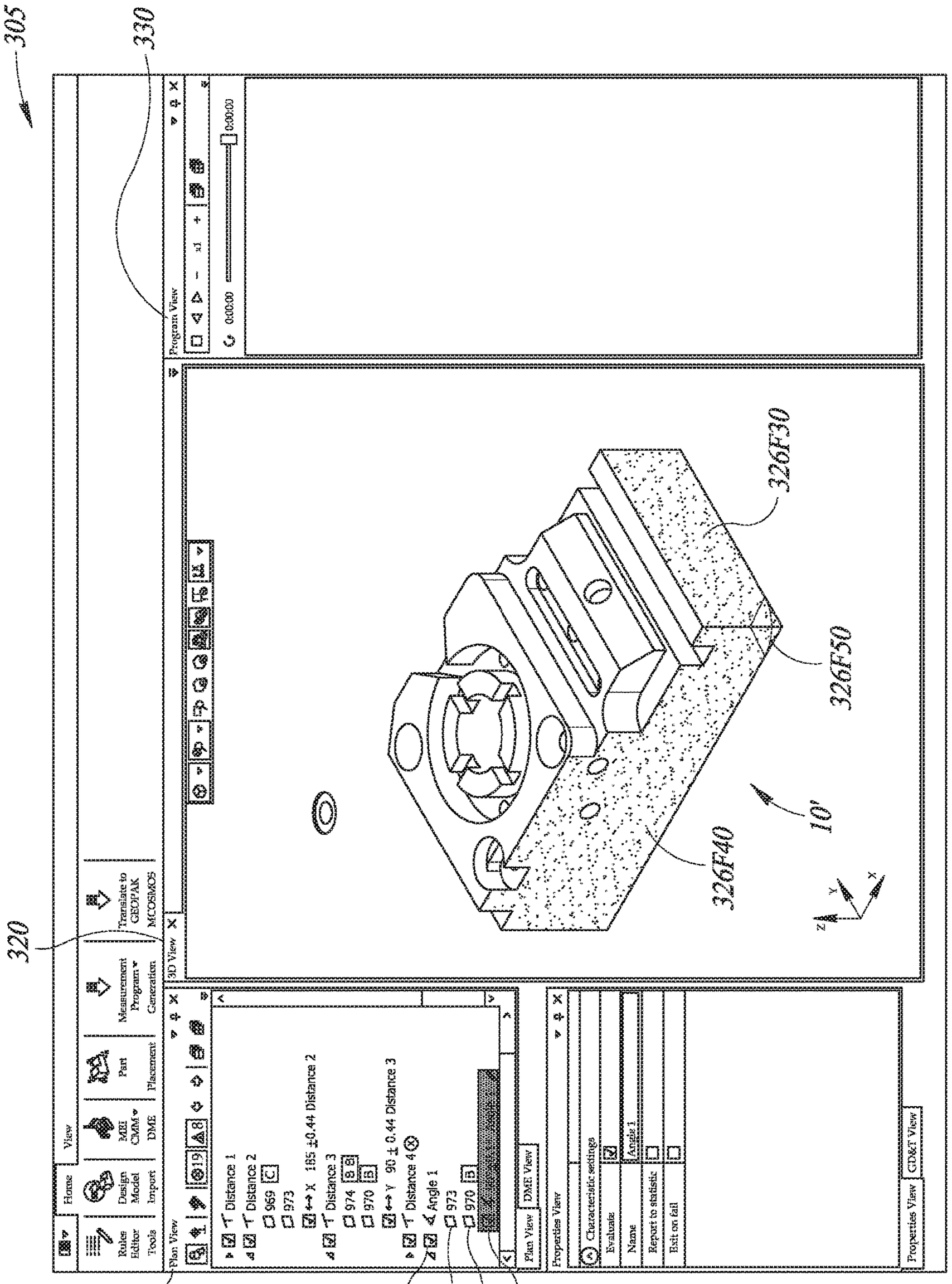
305
330
320
310
316F50
316F30
316F40
316F50C
326F30
326F50
326F40
10'
Home
View
Rules Editor
Design Model
Import
Tools
MBI
CMM
DME
Part
Placement
Measurement Program
Generation
Translate to GEOPAK
MCOSMOS
Plan View
Distance 1
Distance 2
969
973
185 ±0.44 Distance 2
Distance 3
974
970
95 ±0.44 Distance 3
Distance 4
Angle 1
973
970
DME View
Properties View
Characteristic settings
Evaluate
Name
Angle 1
Report to statistic
Exit on fail
Properties View
GD&T View
3D View
Program View
0:00:00
x1
Z
Y
X

FIG. 7

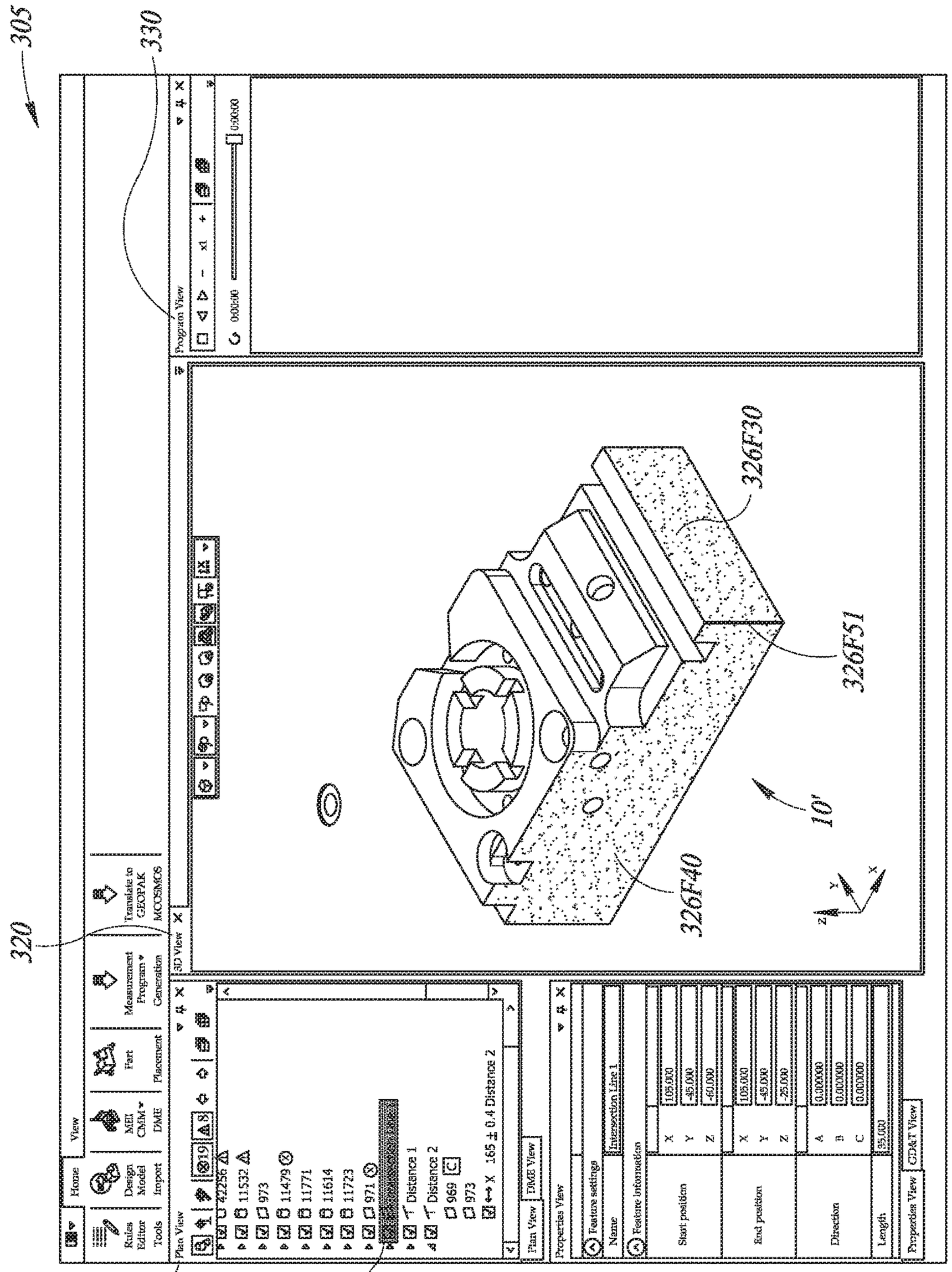
305
330
320
310
326F51
326F30
326F40
10'
Program View
Home
View
Rules Editor
Design Model Import
MEI CMM
DME
Part Placement
Measurement Program Generation
Translate to GEOPAK
MCOSMOS
Plan View
3D View
DME View
Properties View
CD&T View
Feature settings
Feature information
Name
Intersection Line 1
Start position
End position
Direction
Length:
35.000
Distance 1
Distance 2
165 ± 0.4 Distance 2

FIG. 8

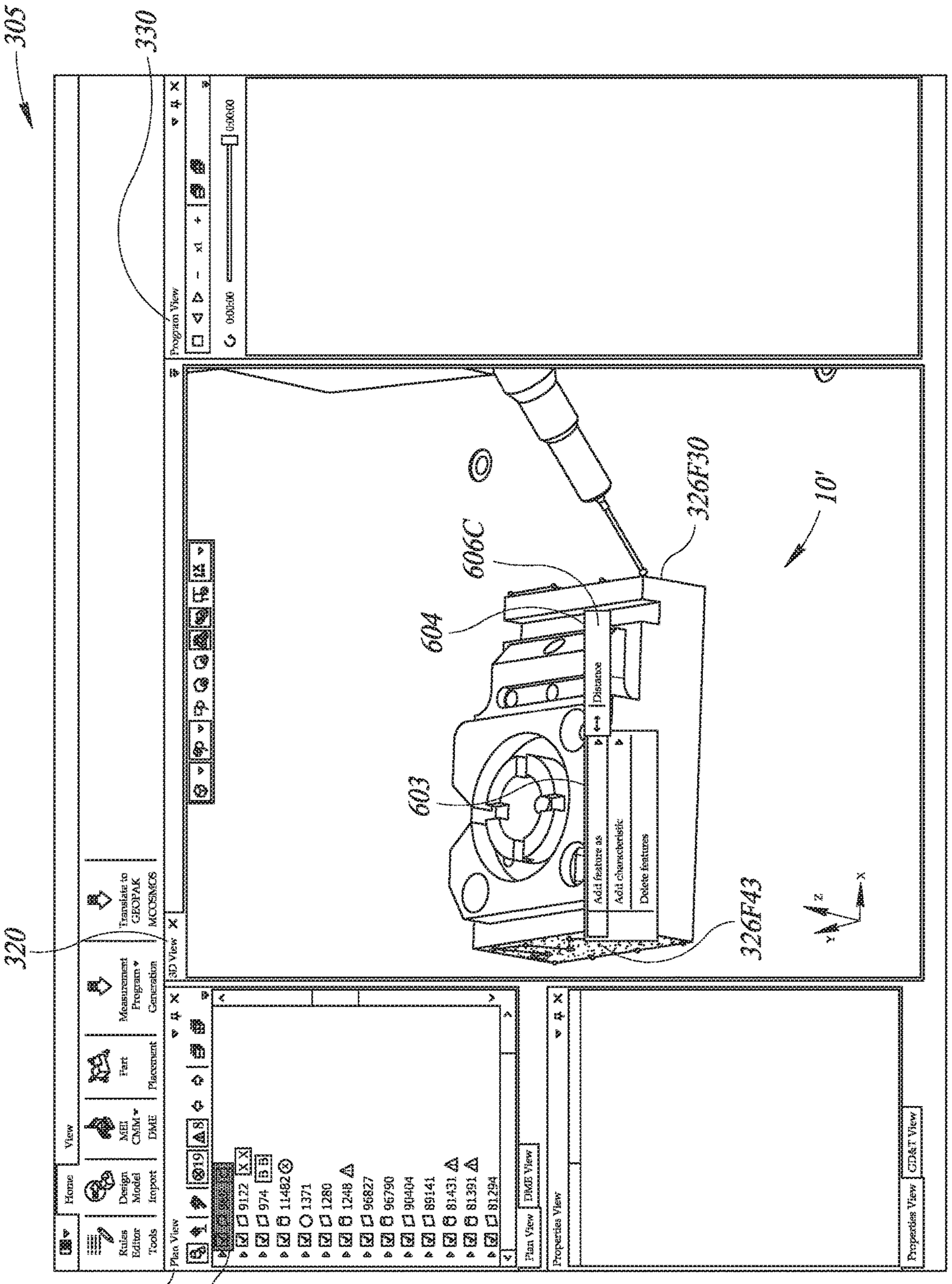
305
330
320
310
326F43
603
604
606C
326F30
10'
Add feature as
Add characteristic
Delete features
Distance
Program View
3D View
Plan View
Properties View
DME View
CDAT View
Translate to GEOPAK
MCOSMOS
Measurement Program Generation
Part Placement
MEI CMM DME
Design Model Import
Rules Editor Tools
Home
View

FIG. 9

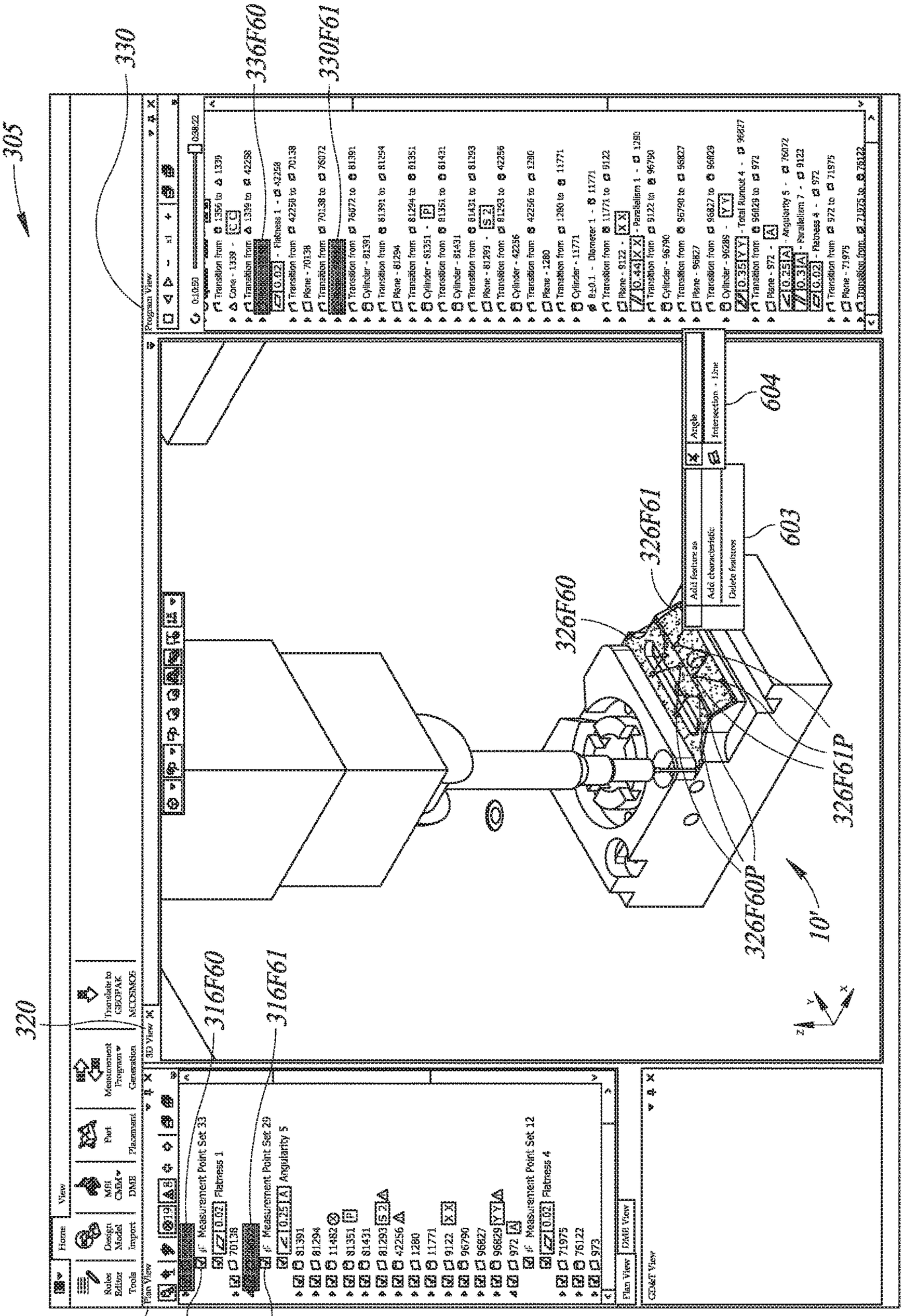
305
330
336F60
330F61
320
310
316F60P
316F61P
316F60
316F61
326F60
326F61
326F60P
326F61P
603
604
10'
Program View
Plan View
3D View
Home
View
Roles Editor
Design Model Import
MSR CMM DMB
Part Placement
Measurement Program Generation
Translate to GEOFAK MCOSMOS
Tools
Angle
Intersection
Add feature as
Add characteristic
Delete features
Measurement Point Set 33
Flatness 1
Measurement Point Set 29
Angularity 5
Measurement Point Set 12
Flatness 4
DMB View
GD&T View

FIG. 10

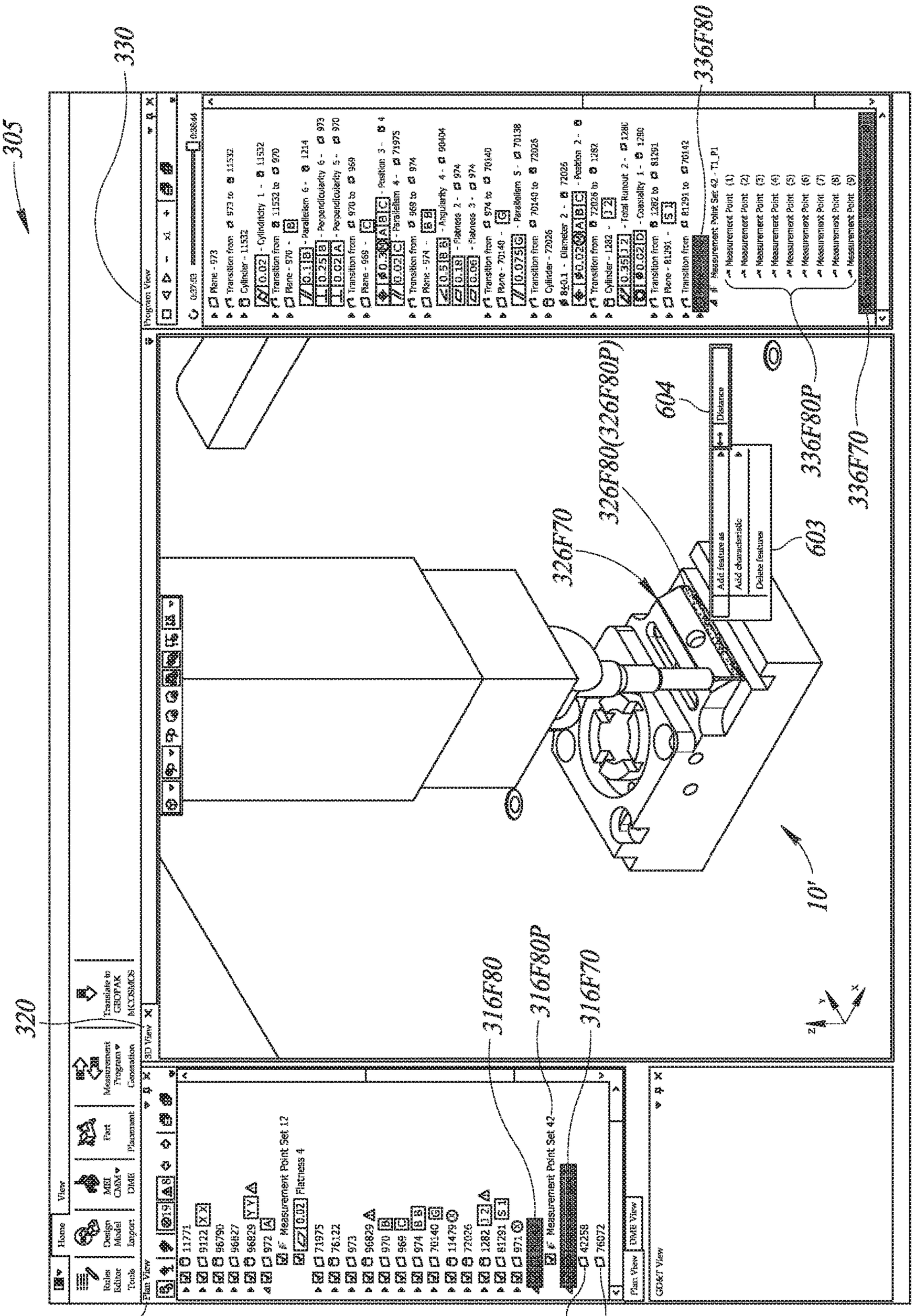
305
330
336F80
Program View
Plane - 973
Transition from 973 to 11532
Cylinder - 11532
0.02 - Cylindricity 1 - 11532
Transition from 11532 to 970
Plane - 970 - B
0.18 - Parallelism 6 - 1214
0.25 B - Perpendicularity 6 - 973
0.02 A - Perpendicularity 5 - 970
Transition from 970 to 969
Plane - 969 - C
Ø0.3 A B C - Position 3 - 4
0.02 C - Parallelism 4 - 71975
Transition from 969 to 974
Plane - 974 - B B
0.5 B B - Angularity 4 - 96404
0.18 - Flatness 2 - 974
0.06 - Flatness 3 - 974
Transition from 974 to 70140
Plane - 70140 - G
0.075 G - Parallelism 5 - 70138
Transition from 70140 to 72026
Cylinder - 72026
Ø40.1 - Diameter 2 - 72026
Ø0.02 A B C - Position 2 - 1282
Transition from 72026 to 1282
Cylinder - 1282 - D 2
0.35 D 2 - Total Runout 2 - 1280
Ø0.02 D - Coaxiality 1 - 1280
Transition from 1282 to 81291
Plane - 81291 - S 1
Transition from 81291 to 70142
Measurement Point Set 42 - T1_P1
Measurement Point (1)
Measurement Point (2)
Measurement Point (3)
Measurement Point (4)
Measurement Point (5)
Measurement Point (6)
Measurement Point (7)
Measurement Point (8)
Measurement Point (9)
326F80(326F80P)
604
326F70
336F80P
336F70
Add feature as
Add characteristic
Delete features
Distance
603
10'
320
Rules Editor
Tools
Design Model
Import
MDI CMM
DMI
Part
Placement
Measurement Program Generation
Translate to GEOPAK MCOSMOS
Plan View
3D View
11771
9122 X X
96790
96827
96829 Y Y A
972 A
Measurement Point Set 12
0.02 Flatness 4
71975
76122
973
96829 A
970 B
969 C
974 B B
70140 G
11479
72026
1282 D 2 A
81291 S 1
971
Measurement Point Set 42
42258
76072
316F80
316F70
316F60
316F61
310
DME View
GD&T View

FIG. 11

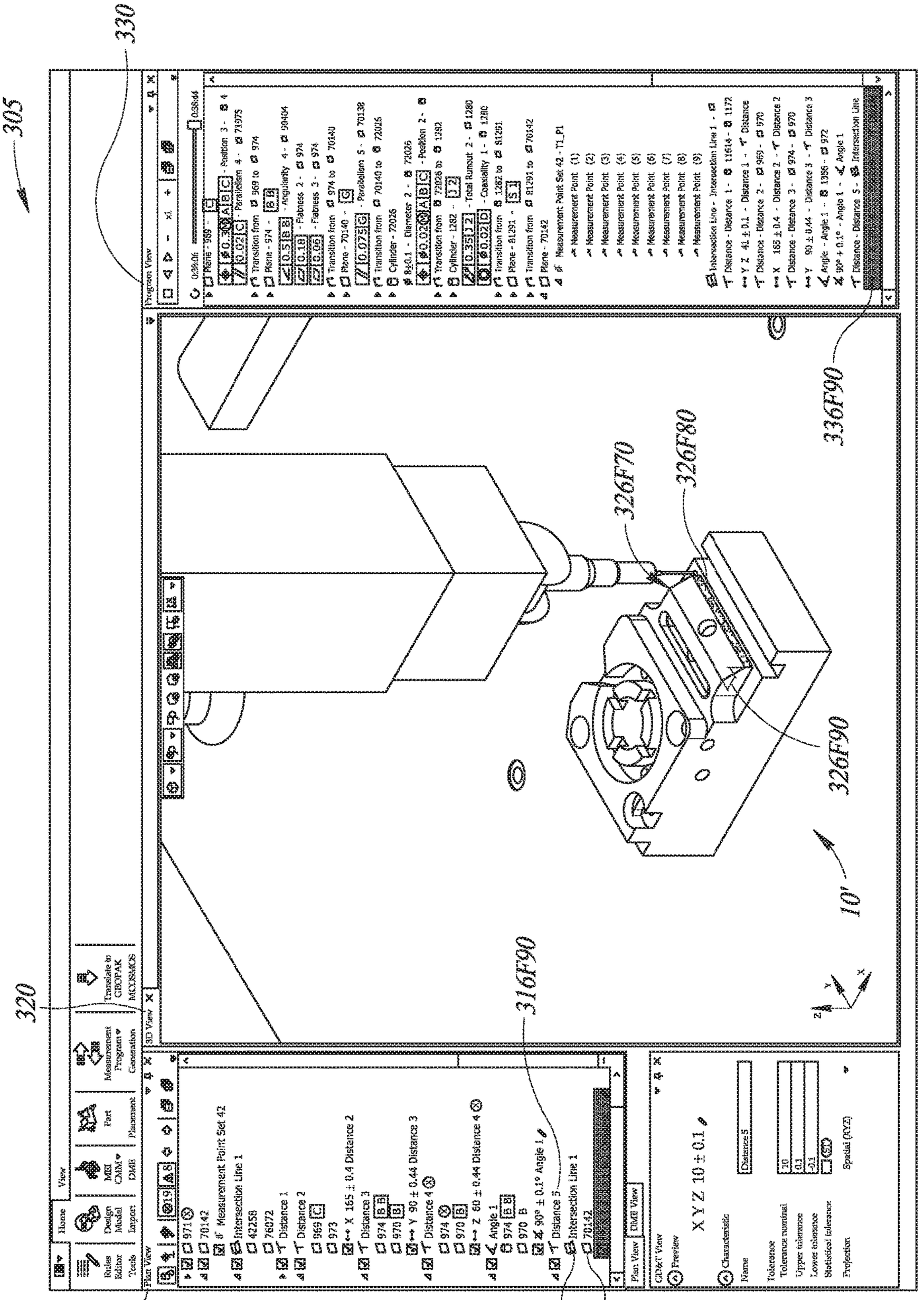
305
330
336F90
326F70
326F80
326F90
10'
320
310
316F70
316F80
316F90
Program View
Plan View
3D View
Home
View
Rules Editor
Design Model Import
MBI CMM DMB
Part Placement
Measurement Program Generation
Translate to GEOPAK MOSS/MOS
Tools
Plane - 969
Transition from 969 to 974
Plane - 974
Transition from 974 to 70140
Plane - 70140
Cylinder - 72026
Transition from 72026 to 1282
Cylinder - 1282
Transition from 1282 to 81291
Plane - 81291
Transition from 81291 to 70142
Plane - 70142
Measurement Point Set 42 - T1_P1
Measurement Point (1)
Measurement Point (2)
Measurement Point (3)
Measurement Point (4)
Measurement Point (5)
Measurement Point (6)
Measurement Point (7)
Measurement Point (8)
Measurement Point (9)
Intersection Line - Intersection Line 1
Distance - Distance 1
Distance - Distance 2
Distance - Distance 3
Distance - Distance 5
Angle - Angle 1
Intersection Line 1
Measurement Point Set 42
Distance 1
Distance 2
Distance 3
Angle 1
Distance 5
CDMT View
Preview
XYZ 10 ± 0.1
Characteristic
Name
Distance 5
Tolerance
Tolerance nominal
10
Upper tolerance
0.1
Lower tolerance
-0.1
Statistical tolerance
GD
Projection
Spatial (XYZ)

FIG. 12

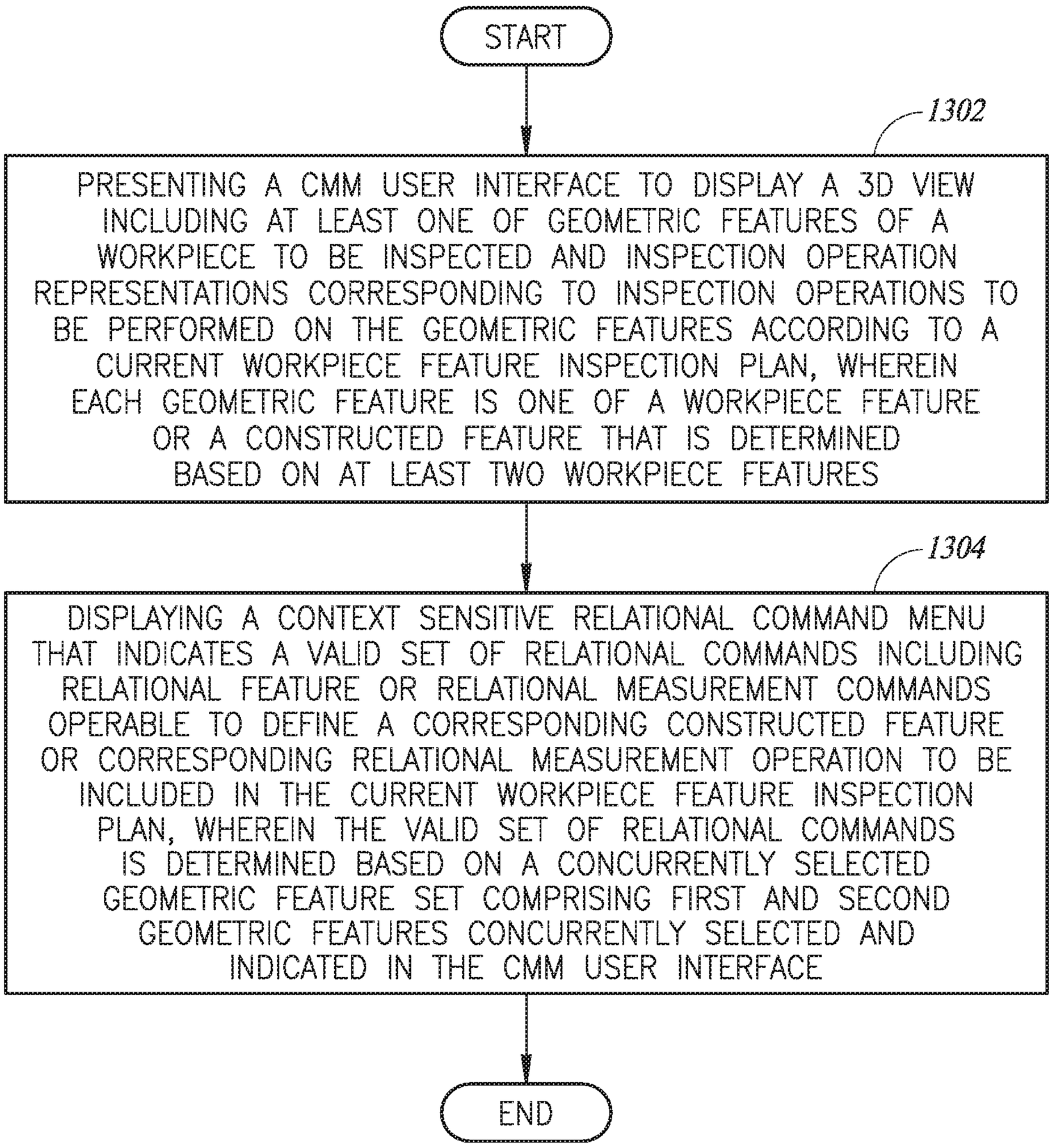
START
1302
PRESENTING A CMM USER INTERFACE TO DISPLAY A 3D VIEW INCLUDING AT LEAST ONE OF GEOMETRIC FEATURES OF A WORKPIECE TO BE INSPECTED AND INSPECTION OPERATION REPRESENTATIONS CORRESPONDING TO INSPECTION OPERATIONS TO BE PERFORMED ON THE GEOMETRIC FEATURES ACCORDING TO A CURRENT WORKPIECE FEATURE INSPECTION PLAN, WHEREIN EACH GEOMETRIC FEATURE IS ONE OF A WORKPIECE FEATURE OR A CONSTRUCTED FEATURE THAT IS DETERMINED BASED ON AT LEAST TWO WORKPIECE FEATURES
1304
DISPLAYING A CONTEXT SENSITIVE RELATIONAL COMMAND MENU THAT INDICATES A VALID SET OF RELATIONAL COMMANDS INCLUDING RELATIONAL FEATURE OR RELATIONAL MEASUREMENT COMMANDS OPERABLE TO DEFINE A CORRESPONDING CONSTRUCTED FEATURE OR CORRESPONDING RELATIONAL MEASUREMENT OPERATION TO BE INCLUDED IN THE CURRENT WORKPIECE FEATURE INSPECTION PLAN, WHEREIN THE VALID SET OF RELATIONAL COMMANDS IS DETERMINED BASED ON A CONCURRENTLY SELECTED GEOMETRIC FEATURE SET COMPRISING FIRST AND SECOND GEOMETRIC FEATURES CONCURRENTLY SELECTED AND INDICATED IN THE CMM USER INTERFACE
END

FIG. 13

CONTEXT SENSITIVE RELATIONAL FEATURE/MEASUREMENT COMMAND MENU DISPLAY IN COORDINATE MEASUREMENT MACHINE (CMM) USER INTERFACE

BACKGROUND

Technical Field

This disclosure relates to precision metrology, and more particularly to inspection programs for coordinate measuring machines.

Description of the Related Art

Certain metrology systems including coordinate measurement machines (CMMs) can be utilized to obtain measurements of inspected workpieces and may be controlled at least in part by workpiece feature inspection operations that have been programmed on a computer. One exemplary prior art CMM is described in U.S. Pat. No. 8,438,746 ("the '746 patent"), which is incorporated herein by reference in its entirety. As described in the '746 patent, the CMM includes a probe for measuring a workpiece, a movement mechanism for moving the probe, and a controller for controlling the movement mechanism.

A CMM which includes a surface scanning probe is described in U.S. Pat. No. 7,652,275, which is incorporated herein by reference in its entirety. After a scan, a three dimensional profile of the workpiece is provided. The workpiece may be measured by a mechanical contact probe scanning along the workpiece surface, or by an optical probe which scans a workpiece without physical contact. Optical probes may be of a type that may use points of light for detecting surface points (such as triangulation probes), or a type that uses a video camera, wherein the coordinates of geometric elements of the workpiece are determined via image processing software. A "combined" CMM that uses both optical and mechanical measuring is described in U.S. Pat. No. 4,908,951, which is incorporated herein by reference in its entirety.

In all of the above described CMMs, operations may be programmed for inspecting workpiece features. The workpiece features and certain CMM components may be represented in computer aided design (CAD) files. The programmed operations for inspecting the workpiece features may generally be reviewed to see which workpiece features are being inspected and in what order, and may also be edited by adding, removing or otherwise altering particular program operations that are associated with particular workpiece features. The applicant of the present patent application has previously disclosed innovative techniques to make such programming, reviewing and editing operations easy for a user to perform or to understand, such that the user may readily program CAD models for workpiece features and/or CMM components in CMM programming systems. See, co-assigned U.S. patent application Ser. No. 14/682,976, filed Apr. 9, 2015, titled "Inspection Program Editing Environment Including Real-Time Feedback Related to Throughput", Ser. No. 14/702,538, filed May 1, 2015, titled "Inspection Program Editing Environment with Simulation Status and Control Continually Responsive to Selection Operations", and Ser. No. 14/703,814, filed May 4, 2015, titled "Inspection Program Editing Environment with Editing Environment Automatically Globally Responsive to Editing Operations in Any of its Portions," all of which are explicitly incorporated herein by reference. Briefly, in those CMM programming systems disclosed in applicant's prior applications, a 3D view window that displays a CAD model, an editable plan view window that allows user editing of a workpiece feature inspection plan organized in terms of workpiece features to be inspected, and a program view window that allows user editing of program pseudo-code, actual code or their graphical representations, are linked together. The three user interface windows are configured to be automatically globally responsive to editing operations performed in any of the three windows. Thus, when edits or changes are applied in any of the windows, the other two windows are automatically cross-updated to present a coherent feedback, in real time, to the user performing the editing in one of the windows. Accordingly, the user may readily track where and how such programmed operations fit within an overall inspection plan or to understand the various effects that certain types of edits may produce relative to the inspection of a particular workpiece feature or for the overall inspection plan.

A need exists for a system and a method that further simplify programming, reviewing and editing operations of CMM workpiece feature inspection programs.

BRIEF SUMMARY

Currently available CMM programming systems provide a tool-bar user interface, in which multiple video tools, or tools for short, are presented for user selection. A typical tool bar may include, for example, a distance tool configured to measure a distance between two workpiece features, an angularity tool configured to measure an angle between two lines or planes, a roundness tool configured to measure roundness of a cylinder or circle, a flatness tool configured to measure flatness of a surface, a concentricity tool configured to measure concentricity of cylinders or circles, a parallelism tool configured to measure parallelism of lines or planes, a perpendicularity tool configured to measure perpendicularity between two lines or planes, etc.

For example, when a user wishes to measure an angle between two planes of a workpiece, the user first selects an angularity tool from the tool bar, which in turn prompts the user to select two workpiece features (e.g., planes or lines) of the workpiece whose assuming angle is to be measured. Similarly, when a user wishes to measure parallelism, the user must first select a parallelism tool from the tool bar, which in turn prompts the user to select two workpiece features (e.g., planes or lines) of the workpiece, whose parallelism is to be measured.

Oftentimes users, in particular relatively unskilled users, may not have a clear vision of workpiece inspection or a solid grasp of programming needed to be able to select the right tool from amongst multiple tools presented in the tool bar. In the example of measuring an angle between two planes of a workpiece, the user must first make a conscious decision to select the angularity tool, then the two planes, which in turn limits the measurement operation to be performed relative to the selected two planes to only the angularity measurement. Relatively unskilled users in particular, however, are often unaware of what measurement operations are possible between multiple workpiece features or, more broadly, what information may be obtainable to characterize a relationship between multiple workpiece features. Those users may be unable to realize to measure an angle between two planes, hence unable to select the angularity tool from the tool bar. Conversely, those users may incorrectly select the angularity tool when, for the purpose

of effective workpiece inspection, relational characteristics other than the angle between the two planes should be defined or measured.

Various embodiments of the present invention provide a system and method including a novel user interface configured to display a context sensitive relational command menu. The context sensitive relational command menu indicates a valid set of relational commands determined based on a concurrently selected geometric feature set including at least two geometric features concurrently selected and indicated in the user interface. The relational commands include one or more relational feature commands operable to define a corresponding constructed feature based on the concurrently selected geometric feature set, wherein the constructed feature is to be included in a workpiece feature inspection plan. The relational commands additionally or alternatively include one or more relational measurement commands operable to define a corresponding relational measurement operation based on the concurrently selected geometric feature set, wherein the relational measurement operation is to be included in the workpiece feature inspection plan.

For example, when a user concurrently selects two workpiece planes to be inspected, the two workpiece planes are in the selected geometric feature set and are so indicated in the user interface, for example, highlighted or shown in a different color than the rest of the workpiece in the user interface. The context sensitive relational command menu is displayed, which indicates a valid set of relational commands determined based on the concurrently selected two workpiece planes. The valid set of relational commands may include, for example, an "intersection line" command operable to define an intersection line, which is a constructed feature based on the concurrently selected two workpiece planes, or an "angle" command operable to define a relational measurement operation to measure an angle between the concurrently selected two workpiece planes. The "intersection line" defined by the relational feature command and the "angle" measurement operation defined by the relational measurement command are, if selected, included in the current workpiece feature inspection plan. A user, in particular a relatively unskilled user, may thus readily understand that, with respect to the concurrently selected two workpiece planes, an intersection line may be defined and an angle may be measured, and may make an appropriate selection of the desired relational command from the menu.

In one aspect, a system is provided for programming workpiece feature inspection operations for a coordinate measuring machine (CMM). The CMM includes at least one sensor used for determining workpiece feature measurement data, a stage for holding a workpiece wherein at least one of the sensor or the stage are movable relative to one another, and a CMM control portion. The system includes generally four components: a computer aided design (CAD) file processing portion, a geometric relationship analyzer, an inspection motion path generation portion, and a user interface.

The CAD file processing portion inputs or generates a workpiece CAD file corresponding to a workpiece, and analyzes the file to automatically determine inspectable workpiece features on the workpiece corresponding to a plurality of geometric feature types, such as lines, planes, circles, cylinders, spheres, cones, etc.

The geometric relationship analyzer performs geometric analysis operations, including geometric analysis operations usable to analyze relational features that are based on a geometric feature set comprising at least two geometric features. There are two types of geometric features: one is a workpiece feature and the other is a constructed feature that is determined based on at least two workpiece features. For example, workpieces features may be lines, planes, circles, cylinders, spheres, cones, etc. of a workpiece to be inspected, and constructed features may be a point of intersection, a line of intersection, a circle of intersection (e.g., between a plane and a cylinder), an overlapping plane, an overlapping volume, a concentric axis, etc. determined based on at least two workpiece features.

The inspection motion path generation portion automatically generates at least part of an inspection motion path used in an inspection program generated by the system based on a current workpiece feature inspection plan for inspecting the workpiece represented by the workpiece CAD file.

The user interface includes an editable plan representation of the current workpiece inspection plan for the workpiece corresponding to the CAD file, wherein the editable plan representation includes at least one of geometric features (workpiece features and/or constructed features) and inspection operation representations (e.g., an "angle" measurement operation representation, a "distance" measurement operation representation, etc.). The user interface also includes a workpiece inspection program simulation portion configured to display a 3D view including at least one of geometric features and inspection operation representations corresponding to inspection operations to be performed on geometric features according to the current workpiece feature inspection plan. The user interface further includes a context sensitive menu portion configured to display a context sensitive relational command menu that indicates a valid set of relational commands. The valid set of relational commands includes relational feature or relational measurement commands, operable to define a corresponding constructed feature or corresponding relational measurement operation to be included in the current workpiece feature inspection plan. The valid set of relational commands is determined based on a concurrently selected geometric feature set including at least two geometric features concurrently selected and indicated in the user interface.

In one aspect, a context sensitive relational command menu is configured to indicate the valid set of relational commands by at least one of: a) limiting the relational commands displayed in the context sensitive relational command menu to the valid set, b) presenting valid and invalid relational commands in different respective formats in the relational command menu, or c) making invalid relational commands inoperable in the relational command menu.

In another aspect, in at least one operating configuration, a complete list of relational commands operable for at least two geometric features, such as the prior art tool bar including all video tools supported by the system, is not displayed. The context sensitive relational command menu includes a first subset and excludes a second subset of the relational commands in the complete list. The first subset includes the one or more valid relational commands, and the second subset excluded from the menu includes one or more invalid relational commands for the concurrently selected geometric feature set.

In another aspect, the valid set of relational commands indicated in the context sensitive relational command menu differs depending on an analysis of the relational features that are based on the concurrently selected geometric feature set, or depending on a geometric relationship or spatial orientation between the at least two geometric features included in the concurrently selected geometric feature set.

In yet another aspect, in response to selection of a valid relational command from the context sensitive relational command menu, the 3D view is automatically updated to display an indication of the corresponding constructed feature or corresponding relational measurement operation to be included in the current workpiece feature inspection plan. Additionally, in response to selection of the valid relational command from the context sensitive relational command menu, the editable plan representation of the workpiece feature inspection plan is automatically updated correspondingly.

According to a further aspect, a method is provided for programming workpiece feature inspection operations for a coordinate measuring machine (CMM). The method includes generally two steps.

First, a CMM user interface is presented to display a 3D view including at least one of geometric features of a workpiece to be inspected and inspection operation representations corresponding to inspection operations to be performed on the geometric features according to a current workpiece feature inspection plan. Each geometric feature is one of a workpiece feature or a constructed feature that is determined based on at least two workpiece features.

Second, a context sensitive relational command menu is displayed, which indicates a valid set of relational commands comprising relational feature or relational measurement commands, operable to define a corresponding constructed feature or corresponding relational measurement operation to be included in the current workpiece feature inspection plan. The valid set of relational commands is determined based on a concurrently selected geometric feature set including first and second geometric features concurrently selected and indicated in the CMM user interface.

It will be appreciated that in prior systems and methods, a user was/is required to first select a measurement/definition tool from a display of all such tools available in the system, such as an angle measurement tool or a distance measurement tool, and thereafter select the workpiece features to which they had hoped to be apply their selected measurement/definition tool. Only after all these steps would a user learn whether the selected tool and the selected workpiece features were in fact compatible. On the other hand, in accordance with various embodiments of the present invention, a user first selects two or more geometric features, and a context sensitive relational command menu is displayed indicating a valid set of relational commands that are automatically selected or determined to be compatible (that is, valid operationally) with the concurrently selected two or more geometric features. Thus, users, in particular relatively unskilled users, may readily understand what types of relational features may be determined from the concurrently selected two or more geometric features and what types of measurement operations may be performed between the concurrently selected two or more selected geometric features, and immediately make an appropriate selection of the desired relational feature/measurement command from the menu without uncertainty or error.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram showing various typical components of a metrology system comprising a CMM.

FIGS. **2**A and **2**B are diagrams showing various elements of one embodiment of a computing system on which workpiece feature inspection operations may be programmed for the CMM of FIG. **1**.

FIG. **3** is a diagram of a user interface including three view portions—an editable plan representation view ("Plan View"), a workpiece inspection program simulation portion view ("3D View"), and an (editable) program view ("Program View")—which are automatically globally responsive to editing operations performed in any of the three view portions, which respectively indicate inspection operations of a workpiece according to a current workpiece feature inspection plan.

FIG. **4** is a diagram of the user interface in which one (first) geometric feature of the workpiece of FIG. **3** is selected.

FIG. **5** is a diagram of the user interface in which another (second) geometric feature of the workpiece of FIG. **3** is concurrently selected as with the first geometric feature.

FIG. **6** is a diagram of the user interface including a context sensitive relational command menu that indicates a valid set of relational commands—an "angle" measurement operation command and an "intersection line" feature construction command—, which are determined based on the first and second geometric features concurrently selected and indicated in the user interface as in FIG. **5**.

FIG. **7** is a diagram of the user interface updated in response to selection of the "angle" measurement operation command from the context sensitive relational command menu of FIG. **6**, indicating that that the angle measurement operation is added to the current workpiece feature inspection plan.

FIG. **8** is a diagram of the user interface updated in response to selection of the "intersection line" feature construction command from the context sensitive relational command menu of FIG. **6**, indicating that the constructed "intersection line" feature is added to the current workpiece feature inspection plan.

FIG. **9** is a diagram of the user interface in which two geometric features different from those in FIG. **5** are concurrently selected, and a context sensitive relational command menu different from that of FIG. **6** is displayed, which includes a "distance" measurement operation command.

FIG. **10** is a diagram of the user interface in which an "intersection line" feature construction command is selected from a context sensitive relational command menu based on two concurrently selected geometric features (e.g., two adjacent surfaces, each defined by a set of feature measurement points).

FIG. **11** is a diagram of the user interface in which the "intersection line" feature is constructed in response to selection of the "intersection line" feature construction command from the context sensitive relational command menu of FIG. **10** and selected, another geometric feature (a surface defined by a set of feature measurement points) is concurrently selected, and a context sensitive relational command menu based on the concurrently selected geometric features is displayed including a "distance" measurement operation command.

FIG. **12** is a diagram of the user interface updated in response to selection of the "distance" measurement operation command from the context sensitive relational command menu of FIG. **11**, indicating that the distance measurement operation is added to the current workpiece feature inspection plan.

FIG. **13** is a flow diagram illustrating one exemplary implementation of a routine for programming workpiece feature inspection operations for a coordinate measuring machine (CMM), including use of a context sensitive relational command menu.

DETAILED DESCRIPTION

FIG. **1** is a diagram showing various typical components of a metrology system **1** including a generic CMM, which provides one context for application of the principles disclosed herein. Certain aspects of the metrology system **1** are further described in the '746 patent. The metrology system **1** may include: a CMM body **2**; a motion controller **3** that controls a drive of the coordinate measuring machine body **2**; an operating unit **4** for manually operating the coordinate measuring machine body **2**; and a host computer **5** that issues commands to the motion controller **3** and executes processing such as for the inspection of features on a workpiece **10** (an object to be measured) disposed on the CMM body **2**. A representative input unit **61** and output unit **62** are connected to the host computer **5**, as well as to a display unit **5**D. The display unit **5**D may display a user interface, for example as described further below with respect to FIGS. **3-12**.

The CMM body **2** may include: a probe **21** having a stylus **21**T which may contact a surface of the workpiece **10**; a movement mechanism **22** that includes a three-axis slide mechanism **24** that holds the base end of the probe **21**; a measurement stage **23** that holds the workpiece **10** and on which a drive mechanism **25** moves the slide mechanism **24**. In various implementations, the drive mechanism **25** may be controlled by a CMM control portion (e.g., including the motion controller **3**). In various implementations one or more sensors of the CMM (e.g., including the probe **21** and/or stylus **21**T) may be moved relative to the measurement stage **23** (e.g., as controlled by the motion controller **3**) and utilized for determining workpiece feature measurement data (e.g., with regard to physical dimensions of features of the workpiece **10**).

FIGS. **2**A and **2**B are diagrams of a computing system **105** including one embodiment of a programming portion **202** on which workpiece feature inspection operations may be programmed for a CMM (e.g., the CMM body **2** of FIG. **1**). In various implementations, the computing system **105** and/or other associated computer system(s) may include suitable unitary or distributed computing systems or devices, which may include one or more processors (hardware) that execute software to perform the functions described herein. Processors include programmable general-purpose or special-purpose microprocessors, programmable controllers, application-specific integrated circuits (ASICs), programmable logic devices (PLDs), or the like, or a combination of such devices. Software may be stored in a memory portion, such as random access memory (RAM), read-only memory (ROM), flash memory, or the like, or a combination of such components. Software may also be stored in one or more storage devices, such as disk drives, solid-state memories, or any other medium for storing data. Software may include one or more program modules which include routines, programs, objects, components, data structures, and so on that perform particular tasks or implement particular abstract data types. In distributed computing environments, the functionality of the program modules may be combined or distributed across multiple computing systems or devices and in various implementations may be accessed via service calls.

As shown in FIG. **2**A, in various implementations the computing system **105** (e.g., the computer **5** of FIG. **1** or a separate computer) may include a memory portion **170**, a display portion **175**, a processing portion **180**, an input-output devices portion **185** and the programming portion **202**. The memory portion **170** includes resident programs and other data utilized by the computing system **105**. The display portion **175** provides the display for the computing system **105** (e.g., similar to the display unit **5**D of FIG. **1**), including the display features provided by the programming portion **202**. The processing portion **180** provides for the signal processing and control of the computing system **105**, while the input-output devices portion **185** receives and provides control signals and outputs to and from various devices (e.g., the CMM controller **3** of FIG. **1**).

As shown in FIG. **2**A, in one embodiment, the programming portion **202** includes a CAD file processing portion **205**, an inspection path and/or sequence manager **206**, a plan view editing user interface portion **210**, a 3D view portion **220**, a program view editing user interface portion **230**, an editing operations portion **240**, which may include an inspection plan modification notices portion **249**, an "other" operations portion **250** including other (non-editing related) operations relevant to the use and functioning of the programming portion **202** and/or computing system **105**, a programming environment synchronization and/or notices manager **260**, a context sensitive menu processing portion **270**A and a context sensitive menu user interface (UI) portion **270**B which are configured to cooperatively generate a context sensitive relational command menu **270**C, and a simulation status and control portion **280**.

In various implementations, the computer-aided design (CAD) file processing portion **205** inputs or generates a workpiece CAD file corresponding to a workpiece (e.g., the workpiece **10** of FIG. **1**) and analyzes the file to automatically determine inspectable workpiece features on the workpiece corresponding to a plurality of geometric feature types (e.g., cylinder, plane, sphere, cone, etc.). The inspection path/sequence manager **206** may automatically determine a motion control path that allows the CMM to obtain measurements that characterize the workpiece features. Methods usable for implementing the CAD file processing portion **205** and/or the inspection path/sequence manager **206** are known in the art, as exemplified in various commercial CAD products, and/or in CAD "extension programs" for creating inspection programs and/or other known CMM inspection programming systems and/or systems which automatically generate machine tool programs from CAD data. For example, U.S. Pat. Nos. 5,465,221; 4,901,253; 7,146,291; 7,783,445; 8,302,031; 5,471,406 and 7,058,472, each of which is hereby incorporated herein in their entirety, disclose various methods which may be used to analyze CAD data and determine geometric features of a workpiece and then automatically generate a motion control path for placing a probe or sensor at inspection points that measure or characterize the geometric features. In some embodiments, determining the geometric features may simply comprise extracting or recognizing the categorized geometric features inherently defined in some modern CAD systems. In some embodiments, product and manufacturing information (PMI, for short) is present in the CAD data, and may be used in the aforementioned processes. PMI conveys non-geometric attributes in CAD data, and may include geometric dimensions and tolerances, surface finish, and the like. In some embodiments, in the absence of PMI, default tolerances and other default inspection rules may be used in automatic operations of the CAD file processing portion **205** and the inspection path/sequence manager **206**.

The motion control path may generally define a feature inspection sequence as well as individual inspection points (e.g., touch probe measurement points, or non-contact measurement points, or point cloud determination regions, etc.), as well as the motion path between such points. In some

embodiments, the CAD file processing portion **205** may include the inspection path/sequence manager **206**, or they may be merged and/or indistinguishable. In one embodiment, one or both of the aforementioned automatic processes may be automatically triggered when a target CAD file is identified in the programming portion **202**. In other embodiments, one or both of the aforementioned automatic processes may be triggered in relation to a target CAD file based on operator input that initiates the processes. In other less desirable embodiments, similar processes may be semi-automatic and require user input in the programming portion **202** for certain operations or decisions.

In any case, in various embodiments the aforementioned processes may, in effect, be used to provide a comprehensive inspection plan and/or inspection program for a workpiece. In some contexts, the connotations of the term "inspection plan" may encompass primarily what features are to be inspected and what measurements are to be made on each, and in what sequence, and the connotations of the term "inspection program" may primarily encompass how the inspection plan is to be accomplished on a particular CMM configuration (e.g., following the "instructions" inherent in the inspection plan, but also including the motion speeds and path, the probe or sensor to be used, and so on for a defined CMM configuration.) Other portions of the programming portion **202** may use the results of the CAD file processing portion **205** and the inspection path/sequence manager **206** to perform their operations and populate and/or control their associated user interface portions, and the like. The plan view editing user interface portion **210** includes an editable plan representation of a workpiece feature inspection plan for the workpiece corresponding to the CAD file. In various implementations, the program view editing user interface portion **230** may also (or instead) include an editable plan representation.

In the CMM programming systems disclosed in co-assigned U.S. patent applications Ser. Nos. 14/682,976, 14/702,538, and 14/703,814 incorporate herein above, visualization of the effect of editing changes to the inspection plan and/or inspection program is immediately or continuously available in real time in the user interface (e.g., through a displayed 3D simulation). For example, FIG. **3** is a diagram of a user interface **305** (e.g., as may be shown on the display unit **5**D of FIG. **1**, the display portion **175** of FIG. **2**A, etc.), including three view portions: an editable plan representation ("Plan View") **310** supported by the plan view editing user interface portion **210**, a "3D View" **320** supported by the 3D view portion **220** (alternatively called a workpiece inspection program simulation portion **220**), and a "Program View" **330** supported by the program user interface portion **230**. Editing operations performed in any of the three view portions are immediately incorporated (e.g., automatically or with very minimal effort by the user) into the current version of the inspection plan and/or inspection program, which is then reflected in the various portions of the programming portion **202** and its user interface(s). As a result, these three view portions are automatically globally responsive to editing operations performed in any of the three view portions, which respectively indicate inspection operations of a workpiece **10'** according to the current workpiece feature inspection plan. In the illustrated embodiment, this may be accomplished through the operations of the programming environment synchronization/notices manager **260**, which in one embodiment may be implemented using known "publisher-subscriber" methods, which are sometimes implemented using XML-like languages (e.g., as used for notifications between web pages). In various embodiments, a publisher-subscriber method may be implemented by adapting methods such as a list-based method, or a broadcast-based method, or a content-based method to support the features disclosed herein. In a CMM programming environment, the publishers and subscribers are generally located in the same processing space, and it is possible for the identity of the "subscriber" windows to be known by the "publisher" (e.g., as may be recorded or implemented using the programming environment synchronization/notices manager **260**, for example.)

In one embodiment, determining and/or generating various workpiece features and measurement operations in the CAD file processing portion **205** and the inspection path/sequence manager **206** may include generating and/or sharing a unique identifier for each workpiece feature and measurement operation. When the results from those portions are used in other portions of the programming portion **202**, the various identifiers may also be used or cross-referenced in the other portions to establish relevant associations between corresponding workpiece features and/or inspection operations across the various processing and/or user interface portions.

The user interface of the programming portion **202** includes a set of editing operations (which also include the underlying programming instructions and/or routines), usable to edit the workpiece feature inspection plan and/or inspection program. For example, the user interface operations may include selections of text or graphical elements that represent workpiece features or inspection operations, followed by activation of relevant commands or other user interface operations that affect the selected elements. In one embodiment, the editing operations portion **240** may provide or identify such editing operations. In one embodiment, the inspection plan modification notices portion **249** may be responsive to operations included in the editing operations portion **240** to provide a notice to the programming environment synchronization/notices manager **260** that an inspection plan modification is taking place.

In response, the programming environment synchronization/notices manager **260** may then (e.g., automatically) manage the exchange of various event or programming operation notifications and related unique identifiers, such that the CAD file processing portion **205** and/or the inspection path/sequence manager **206** appropriately edit or modify the current inspection plan and inspection program in a synchronized manner when one of the set of editing operations is performed. Such plan and program modifications may be performed very quickly in various embodiments, because the unique identifiers described above may be used to efficiently focus the modifications on only those features and/or measurement operations affected by the currently active one of the set of editing operations. After that, the programming environment synchronization/notices manager **260** may notify other portions of the programming portion **202** (e.g., any of the plan view editing user interface portion **210**, 3D view portion **220**, and program view editing user interface portion **230**), so that they are immediately updated using information from the edited plan and/or program. The unique identifier(s) of the most recently edited elements may again be used to speed up such operations, in that the updating need only focus on those elements associated with the identifiers.

It should be appreciated that the programming environment synchronization/notices manager **260** may also manage inter-portion communications and exchanges besides those associated with the editing operations. In various embodiments, it may facilitate the synchronization between

the various user interface windows or portions of the programming portion **202**. For example, selection of a particular feature or instruction in one window may automatically trigger a notification or instruction to other windows to display a corresponding feature or instruction in that other window, or depict a program operating state associated with the selected feature or instruction, or the like.

As illustrated in detail in FIG. **2**B, the programming environment synchronization/notices manager **260** may manage inter-portion communications and exchanges between the context sensitive menu processing portion **270**A and the context sensitive menu UI portion **270**B, to achieve generation and display of a context sensitive relational command menu **270**C. The context sensitive relational command menu **270**C indicates a valid set of relational commands based on a concurrently selected geometric feature set including at least two geometric features concurrently selected and indicated in the user interface.

The context sensitive menu processing portion **270**A includes a geometric characteristics analyzer **2701** which may include a geometric relationship analyzer **2702**, which in turn may include a relational measurement analyzer/operations **2703**, relational feature analyzer/operations **2704**, and valid relational feature command set analyzer/operations **2705**. The context sensitive menu processing portion **270**A also includes a selected feature manager **2708** which may include a concurrent selection notification **2709**.

The selected feature manager **2708** is responsible for processing user selection of geometric features of a workpiece, and the concurrent selection notification **2709** is responsible for defining and notifying to other portions of the computing system **105** a concurrently selected geometric feature set comprising at least two geometric features concurrently selected and indicated in the user interface.

The geometric characteristic analyzer **2701** performs geometric analysis operations on geometric features, in particular those selected geometric features under the control of the selected feature manager **2708**. The geometric analysis operations analyze geometric characteristics, such as shape, size, dimensions, orientation, etc. of geometric features usable for the purpose of programming workpiece feature inspection operations. The geometric relationship analyzer **2702** in various implementations determines a valid set of relational commands corresponding to a set of valid geometric relationships that can be determined between the geometric features. Specifically, the geometric relationship analyzer **2702** is operable to perform geometric analysis operations usable to analyze "relational features" that are based on a geometric feature set defined by the concurrent selection notification **2702**. In other words, with respect to at least two geometric features concurrently selected and indicated in the user interface (e.g., in the plan view window **310**, the 3D view window **320**, and/or in the program view window **330**), the geometric relationship analyzer **2702** analyzes and defines "relational features."

The relational features include relational measurement operations that may be performed on or between the concurrently selected geometric features, such as an angle measurement operation (e.g., between two planes, between two lines), and a distance measurement operation (e.g., between two parallel planes, between two parallel volumes). The geometric relationship analyzer **2702** may include relational measurement analyzer/operations **2703** responsible for analyzing and defining the relational measurement operations which can be performed on the concurrently selected geometric features. In some embodiments, the relational measurement analyzer/operations **2703** validate and/or calculate what relational measurement operations are valid for the concurrently selected geometric features. For example, when two concurrently selected planes meet each other, an angle measurement operation is valid but a distance measurement operation may not be valid for these planes. Likewise, when two concurrently selected planes are parallel to each other, a distance measurement operation is valid but an angle measurement operation is invalid for these planes.

The relational features defined by the geometric relationship analyzer **2702** may also include new features to be constructed based on the concurrently selected geometric features. Such new features may include a point of intersection (e.g., between a line and a plane), a line of intersection (e.g., between two planes), a circle of intersection (e.g., between a cylinder and a plane), an overlapping plane (e.g., between two planes), an overlapping volume (e.g., between two volumes), a concentric axis (e.g., between two circles), etc. Those features that can be constructed based on the concurrently selected geometric features are herein called "constructed features." The geometric relationship analyzer **2702** may include relational feature analyzer/operations **2704** responsible for analyzing and defining the constructed features which can be determined or generated based on the concurrently selected geometric features. In some embodiments, the relational feature analyzer/operations **2704** validate and/or calculate what constructed features are valid for the concurrently selected geometric features. For example, when two concurrently selected planes meet each other, an intersection line is a valid constructed feature, but an intersection circle cannot be constructed and thus is an invalid constructed feature.

Note that constructed features based on concurrently selected workpiece features on a workpiece may in turn be used to construct further constructed features. For example, an intersection line constructed based on two concurrently selected planes that meet each other is a constructed feature, and the constructed "intersection line" feature may then be concurrently selected with another line (which may be an original workpiece feature line or may be a constructed feature line), to define yet another constructed "intersection point" feature. As used herein, the term "geometric feature" broadly encompasses workpiece features that are originally defined (e.g., found by the CAD file processing portion **205**) on a workpiece, constructed features built from workpiece features, and further constructed features built from constructed features and/or a combination of constructed features and workpiece features.

Still referring to FIG. **2**B, the geometric relationship analyzer **2702** may further include a valid relational command set analyzer/operations **2705**, which is responsible for determining or activating a valid set of relational commands. The valid set of relational commands include one or more relational measurement commands operable to define corresponding relational measurement operations to be included in a current workpiece feature inspection plan, and/or one or more relational feature commands operable to define corresponding constructed features to be included in the current workpiece feature inspection plan. The valid set of relational measurement commands and relational feature commands for the concurrently selected geometric features is found based on the processing results of the relational measurement analyzer/operations **2703** and the relational feature analyzer/operations **2704**.

The programming environment synchronization/notice manager **260** facilitates the synchronization of the valid set of relational commands, determined by the valid relational

command set analyzer/operations **2705**, with the user interface of the computing system **105**. In various implementations the user interface includes the context sensitive menu UI portion **270**B, the plan view editing interface portion **210**, the 3D view portion **220**, and the program view editing user interface portion **230**. The context sensitive menu UI portion **270**B is configured to display a context sensitive relational command menu (e.g., **604** in FIG. **6**) that indicates the valid set of relational commands, defined by the valid relational command set analyzer/operations **2705**. The valid set of relational commands include relational feature or relational measurement commands operable to define a corresponding constructed feature or corresponding relational measurement operation to be included in the current workpiece feature inspection plan. The context sensitive relational command menu **604** may be displayed anywhere on the display portion **175** of FIG. **2**A (or **5**D of FIG. **1**) of the computing system **105**, including the plan view window **310**, the 3D view window **320**, and the program view window **330**. In some embodiments, as shown in FIG. **6**, the context sensitive relational command menu **604** is displayed adjacent to the geometric features that are concurrently selected and indicated in the user interface, for example in the 3D view window **330**, in order to provide valuable feedback to a user performing inspection plan programming operations. Specifically, a user, in particular a relatively unskilled user, by concurrently selecting two or more geometric features on the user interface of the computing system **105**, is presented with a context sensitive relational command menu **604** adjacent to the concurrently selected geometric features. The menu indicates a valid set of relational commands, from which the user can readily select one command to have its corresponding relational measurement operation or corresponding constructed feature included into the current workpiece feature inspection plan.

FIG. **3** is a diagram of a user interface **305** (e.g., as may be shown on the display unit **5**D of FIG. **1**, the display portion **175** of FIG. **2**A, etc.). It will be appreciated that certain numbered elements **3**XX of the user interface **305** may correspond to and/or be provided by similarly numbered elements **2**XX of FIGS. **2**A and **2**B. In the implementation shown in FIG. **3**, the user interface **305** includes the plan view window ("Plan View") **310**, the 3D view window ("3D View") **320**, and the program view window ("Program View") **330**. The plan view window **310** includes an editing user interface portion **312**, the 3D view window **320** includes a workpiece inspection program simulation portion **322**, and the program view window **330** includes an editing user interface portion **332**. The editing user interface portions **312** and **332** each include plan representations **314** and **334**, respectively, of a workpiece feature inspection plan for a workpiece **10'** corresponding to a CAD file processed in the CAD file processing portion **205**. The plan representation **314** in the "Plan View" is organized in terms of geometric features to be inspected on the workpiece. The plan representation **334** in "Program View" is organized as inspection program pseudo-code or actual code or graphical program operation representations or the like, in various embodiments. In the illustrated embodiment, each or both of the plan representations **314** and **334** are editable (that is, they are editable plan representations.) When editing operations are performed for one of the editable plan representations **314** and **334**, the other plan representation may be automatically updated in a manner consistent with those editing operations by operation of the various system elements illustrated and described with respect to FIGS. **2**A and **2**B. However, in some embodiments, only one of the plan representations **314** and **334** need be editable. In such a case, the other plan representation may be absent, or hidden, or may be displayed and automatically updated.

The editable plan representations **314** and **334** include the editable set of geometric feature, collectively **316** and **336**, to be inspected. In FIG. **3**, the editable plan representation **314** in the "Plan View" presently displays geometric features **316**F**1**~**316**F**21**, though the plan view window **310** is scrollable by a scroll bar **317** to show other portions of the workpiece feature inspection plan. The editable plan representation **334** in the "Program View" presently displays geometric features **336**F**1** and **336**F**8** ("Cylinder—**1214**" followed by a cylinder icon), among others, which respectively correspond to the geometric features **316**F**1** and **316**F**8** displayed in the "Plan View," though it too is scrollable by a scroll bar **337** to show other portions of the workpiece feature inspection plan. The 3D view window **320** displays a 3D view of the workpiece inspection program simulation portion **322** including workpiece features **326** on the workpiece **10'** including the geometric feature **326**F**8** (cylinder) that corresponds to the geometric features **316**F**8** and **336**F**8** displayed in the "Plan View" and "Program View," respectively. The 3D view of the workpiece inspection program simulation portion **322** also includes display of the touch probe **21'** and stylus **21**T' applied to inspect the workpiece **10'**. As will be described in detail below (and as observable in the "Program View"), the editable plan representations **314** and **334** in the "Plan View" and "Program View" as well as the 3D workpiece inspection program simulation portion **322** in the "3D View" may additionally or alternatively include inspection operation representations, for example icons or numeric/text descriptions of inspection operations such as an angle measurement operation and a distance measurement operation.

In the example of FIG. **3**, the geometric feature **326**F**8** (cylinder) in the "3D View" is selected (e.g., by user clicking thereon), and selection of the geometric feature **326**F**8** is indicated by that the corresponding geometric features (cylinders) **316**F**8** and **336**F**8** are highlighted in the "Plan View" and "Program View."

FIG. **4** is a diagram of the user interface **305** of FIG. **3** in which one geometric feature **326**F**30**, which is a plane on the workpiece **10'**, is selected (e.g., by clicking thereon). Selection of the geometric feature **326**F**30** is indicated by the geometric feature **326**F**30** being highlighted in the 3D view window **320**, and correspondingly the geometric feature **316**F**30** is highlighted or otherwise marked in the editable plan representation in the plan view window **310**.

FIG. **5** is a diagram of the user interface **305** in which another (second) geometric feature **326**F**40**, which is also a plane on the workpiece **10'**, is concurrently selected with the already-selected geometric feature **326**F**30** (e.g., by holding a "control" key with the first geometric feature **326**F**30** selected and clicking on the second geometric feature **326**F**40**). The concurrent selection is indicated by both of the geometric features **326**F**30** and **326**F**40** being highlighted in the 3D view window **320**. Correspondingly the geometric feature **316**F**40** is highlighted or otherwise marked in the editable plan representation in the plan view window **310**. In the illustrated example, the concurrently selected (first) geometric feature **316**F**30** is not included in the portion of the editable plan representation currently visible in the plan view window **310**, but if the plan view window were expanded or scrolled, it would be shown to be highlighted or otherwise marked, in various embodiments.

FIG. **6** is a diagram of the user interface **305** in which a context sensitive relational command menu **604** is displayed

indicating a valid set of relational commands for the concurrently selected geometric features **326**F**30** and **326**F**40**. The context sensitive relational command menu **604** includes an "angle" measurement operation command **606**A operable to define an angle measurement operation, with respect to the concurrently selected geometric features, to be included in the current workpiece feature inspection plan, and an "intersection line" feature construction command **606**B operable to define a constructed "intersection line" feature, based on the concurrently selected geometric features, to be included in the current workpiece feature inspection plan. In some embodiments, the context sensitive relational command menu **604** is generated and displayed automatically upon concurrent selection of at least two geometric features. In other embodiments, the context sensitive relational command menu **604** is displayed after, for example, right-clicking on the user interface **305** to display a parent menu **603**, from which an "Add feature as" command is selected to display the context sensitive relational command menu **604** as a submenu. Alternatively to the submenu, a graphical toolbar might offer analogous or equivalent command buttons in some embodiments. As will be apparent to those skilled in the art a particular manner in which the context sensitive relational command menu **604** is displayed (e.g., automatically, semi-automatically, using a menu system having a defined hierarchical depth, etc.) is a matter of implementation according to each application, and the present invention disclosure is not limited to the implementation example illustrated in FIG. **6**. Note that the context sensitive relational command menu **604** does not include, for example, a distance measurement operation command because the distance between the concurrently selected geometric features **326**F**30** and **326**F**40** cannot be defined and hence the distance measurement operation command is not a valid command with respect to these geometric features (e.g., as determined by the geometric relationship analyzer **2702** of FIG. **2**B).

In some implementations, the context sensitive relational command menu **604** is displayed adjacent to the geometric features that are concurrently selected and indicated in the user interface **305**. For example, as shown in FIG. **6**, when the geometric features **326**F**30** and **326**F**40** in the 3D view window **320** are selected, the context sensitive relational command menu **604** is displayed adjacent to the geometric features **326**F**30** and **326**F**40** in the 3D view window **320**. Alternatively, when the corresponding geometric features **316**F**30** and **316**F**40** in the plan view window **310** are selected (e.g., by holding a "control" key with the first geometric feature **316**F**30** selected and clicking on the second geometric feature **316**F**40** in the plan view window **310**), the context sensitive relational command menu **604** may be displayed adjacent to the geometric features **316**F**30** and **316**F**40** in the plan view window **310**.

FIG. **7** is a diagram of the user interface **305**, which is updated in response to selection of the "angle" measurement operation command **606**A from the context sensitive relational command menu **604** of FIG. **6**, indicating that the angle measurement operation **326**F**50** is now added to the current workpiece feature inspection plan. Addition of the angle measurement operation **326**F**50** is graphically or otherwise indicated in the 3D view window **320**. Correspondingly the angle measurement operation **316**F**50**, operable to measure or compute an angle between the two concurrently selected geometric features **316**F**30** and **316**F**40**, is added in the editable plan representation in the plan view window **310**. In the illustrated example, in connection with the angle measurement operation **316**F**50**, measurement criteria or standards for the angle measurement operation **316**F**50**C ("90°±0.1°") are included as part of the current workpiece feature inspection plan in the plan view window **310**. Processing in response to selection of the "angle" measurement operation command **606**A, including incorporation of the angle measurement operation **316**F**50**/**326**F**50** into the current workpiece feature inspection plan and indication of the angle measurement operation **316**F**50**/**326**F**50** in the user interface **305**, is performed, for example, by various components of the CMM workpiece feature inspection operations programming portion **202** and the associated portions and techniques described above in reference to FIG. **2**A.

FIG. **8** is a diagram of the user interface **305**, which is updated in response to selection of the "intersection line" feature construction command **606**B from the context sensitive relational command menu **604** of FIG. **6** (in contrast to the selection of the "angle" measurement operation command **606**A, as discussed above in relation to FIG. **7**), indicating that an intersection line **326**F**51** is now added as a newly constructed feature to the current workpiece feature inspection plan. Addition of the intersection line **326**F**51** is graphically or otherwise indicated in the 3D view window **320**. Correspondingly the "intersection line" feature **316**F**51**, constructed from the concurrently selected geometric features **316**F**30** and **316**F**40**, is added in the editable plan representation in the plan view window **310**. Processing in response to selection of the "intersection line" feature construction command **606**B, including incorporation of the constructed "intersection line" feature **316**F**51**/**326**F**51** into the current workpiece feature inspection plan and indication of the constructed "intersection line" feature **316**F**51**/**326**F**51** in the user interface **305**, is performed, for example, by various components of the CMM workpiece feature inspection operations programming portion **202** and the associated portions and techniques described above in reference to FIG. **2**A.

FIG. **9** is a diagram of the user interface **305**, in which two geometric features **326**F**30** and **326**F**43**, different from the geometric features selected in FIG. **5** (**326**F**30** and **326**F**40**), are concurrently selected. Specifically, the geometric feature **326**F**43**, which is a plane positioned in parallel to the geometric feature **326**F**30** (plane), is concurrently selected (indicated in highlight) as with the geometric feature **326**F**30** in the 3D view window **320**. Correspondingly the geometric feature **316**F**43** (parallel plane) is highlighted or otherwise marked in the editable plan representation in the plan view window **310**. In the illustrated example, the concurrently selected geometric feature **316**F**30** is not included in the portion of the editable plan representation currently visible in the plan view window **310**. The user interface **305** also includes a display of a context sensitive relational command menu **604** which may appear automatically or based on a user input as outlined previously, which indicates a valid set of relational commands for the concurrently selected geometric features **326**F**30** and **326**F**43**. The context sensitive relational command menu **604** in this instance includes a "distance" measurement operation command **606**C operable to define a distance measurement operation, with respect to the concurrently selected geometric features, to be included in the current workpiece feature inspection plan. In the illustrated example, the context sensitive relational command menu **604** is displayed as a submenu from a parent menu **603**, though a particular manner in which the context sensitive relational command menu **604** is displayed is in no way limited to the illustrated implementation example. Note that the context sensitive relational command menu **604** does not include, for example, an angle measurement opera-

tion command or an intersection line feature construction command because no angle or intersection line can be formed between the concurrently selected geometric features **326**F**30** and **326**F**43** (parallel planes). Thus, these commands which were operational in the operating context or situation shown in FIGS. **6**, **7** and **8**, are invalid relational commands for the concurrently selected geometric features **326**F**30** and **326**F**43** in the operating context or situation shown in FIG. **9**, as automatically determined by the geometric relationship analyzer **2702** of FIG. **2**B for example.

As apparent from comparison between the context sensitive relational command menu **604** of FIG. **6** and that of FIG. **9**, the valid set of relational commands including relational feature commands and relational measurement commands differs depending on an analysis of the relational features that are based on the concurrently selected geometric features. The valid set of relational commands may differ depending on a geometric relationship or spatial orientation between the concurrently selected geometric features.

In various implementations, the context sensitive relational command menu **604** is configured to indicate the valid set of relational commands by limiting the relational commands displayed in the context sensitive relational command menu **604** to the valid set only, as shown in FIGS. **6** and **9**. Alternatively or additionally, both valid and invalid relational commands may be displayed in different respective formats in the context sensitive relational command menu **604**. For example, the valid set may be highlighted while the invalid set is not highlighted in the context sensitive relational command menu **604**. Further alternatively or additionally, invalid relational commands in the context sensitive relational command menu **604** may be rendered inoperable, such that user may view and select the invalid relational commands but the invalid relational commands are inoperable even if selected.

Note that for some concurrently selected geometric feature sets, the valid set may be empty and no relational measurement commands or relational feature commands are valid. In such cases the context sensitive relational command menu **604** indicates no valid set of relational commands. For example, the context sensitive relational command menu **604** may be displayed as a blank menu.

The prior art CMM programming systems provide a tool-bar user interface, in which all video tools (e.g., measurement operation tools, feature construction tools) are presented for user selection. In some embodiments of the CMM programming system according to the present disclosure, in at least one operating configuration, a complete list of relational commands (e.g., the prior art tool bar) operable to define a corresponding constructed feature or corresponding relational measurement operation between at least two geometric features is not displayed. The context sensitive relational command menu **604**, which is displayed, includes only a first subset of valid relational commands from the complete list and excludes a second subset of invalid relational commands from the complete list.

In various implementations, the context sensitive relational command menu **604** is generated after two or more geometric features are concurrently selected and indicated in the user interface **305**. In other implementations, it is possible to pre-form various context sensitive relational command menus **604** for various possible sets of concurrently selectable geometric features, any of which can then be called upon selection of a particular set of concurrently selected geometric features.

FIG. **10** is a diagram of the user interface **305**, in which two geometric features **326**F**60** (a first plane) and **326**F**61** (a second adjacent plane) are concurrently selected, and highlighted in the 3D view window **320**. In the example of FIG. **10**, sets of feature measurement points **326**F**60**P and **326**F**61**P (e.g. as automatically determined by various components of the CMM workpiece feature inspection operations programming portion **202**) that are used to measure and characterize the associated geometric features are shown. Such feature measurement point sets may be hidden or displayed when a corresponding feature is selected, in various embodiments and/or display modes of the user interface. As illustrated, the concurrently selected geometric features **316**F**60** and **316**F**61** are also highlighted or otherwise marked in the editable plan representation in the plan view window **310**. In the illustrated example, in connection with the geometric features **316**F**60** and **316**F**61**, the set of feature measurement points **316**F**60**P and **316**F**61**P that respectively are measured and analyzed to define the geometric features **316**F**60** and **316**F**61** are represented in the current workpiece feature inspection plan in the plan view window **310**. Further correspondingly, the concurrently selected geometric features **336**F**60** and **336**F**61** are highlighted or otherwise marked in the editable plan representation in the program view window **330** ("Program View"), in which the current workpiece feature inspection plan is organized as inspection program pseudo-code, actual code, or graphical program operation representations. The user interface **305** also includes a display of a context sensitive relational command menu **604**, which indicates a valid set of relational commands for the concurrently selected geometric features **326**F**60** and **326**F**61**, which may appear automatically or based on a user input, as outlined previously. The context sensitive relational command menu **604** in this instance includes an "angle" measurement operation command and an "intersection line" feature construction command (similar to FIG. **6**) because these are a valid set of relational commands for the concurrently selected geometric features **326**F**60** and **326**F**61**, i.e., a first plane surface and a second plane that intersect or meet each other. In the illustrated example, the context sensitive relational command menu **604** is displayed as a submenu from a parent menu **603**, though a particular manner in which the context sensitive relational command menu **604** is displayed is not limited to the particular implementation example of FIG. **10**. The user interface **305** also indicates that the user has selected the "intersection line" feature construction command from the context sensitive relational command menu **604**, (e.g. by clicking on that command) as indicated by the "intersection line" feature construction command being highlighted.

FIG. **11** is a diagram of the user interface **305**, in which the "intersection line" feature, constructed in response to selection of the "intersection line" feature construction command from the context sensitive relation command menu **604** of FIG. **10**, is added and displayed as a "constructed" or "relational" geometric feature **326**F**70**. Further, the "intersection line" geometric feature **326**F**70** has been selected by a user in the operating state shown in FIG. **11**. Concurrently, a geometric feature **326**F**80** (plane) defined by a corresponding set of feature measurement points **326**F**80**P is also selected. Correspondingly, the concurrently selected geometric features **316**F**70** (i.e., the "intersection line" feature constructed from the geometric features **316**F**60** and **316**F**61**) and **316**F**80** (i.e., the plane defined by the set of feature measurement points **316**F**80**P) are highlighted or otherwise marked in the editable plan representation in the plan view window **310**. Further correspondingly, the concurrently selected geometric features **336**F**70** and **336**F**80**

(defined by the set of feature measurement points **336**F**80**P) are highlighted or otherwise marked in the editable plan representation in the program view window **330**. The user interface **305** also includes a display of a context sensitive relational command menu **604** (which may appear automatically or based on a user input, as outlined previously), which indicates a valid set of relational commands for the concurrently selected geometric features **326**F**70** and **326**F**80**. The context sensitive relational command menu **604** in this instance includes a "distance" measurement operation command because it is a valid operation to measure a distance between the constructed "intersection line" feature **326**F**70** and the geometric feature **326**F**80**, which is a plane separated and distanced, in parallel, from the constructed "intersection line" feature **326**F**70**. The user interface **305** also indicates that the user has selected the "distance" measurement operation command from the context sensitive relational command menu **604**, as indicated by the "distance" measurement command being highlighted.

FIG. **12** is a diagram of the user interface **305**, which is updated in response to selection of the "distance" measurement operation command from the context sensitive relational command menu **604** of FIG. **11**, indicating that the distance measurement operation **326**F**90** is now added to the current workpiece feature inspection plan. Addition of the distance measurement operation **326**F**90** is graphically or otherwise indicated in the 3D view window **320**. Correspondingly the distance measurement operation **316**F**90**, operable to measure or compute a distance between the two concurrently selected geometric features **316**F**70** and **316**F**80**, is added in the editable plan representation in the plan view window **310**. Further correspondingly, the distance measurement operation **336**F**90**, operable to measure a distance between the two concurrently selected geometric features **336**F**70** and **336**F**80** (not currently visible), is added in the editable plan representation in the program view window **330**. Processing in response to selection of the "distance" measurement operation command, including incorporation of the distance measurement operation **316**F**90**/**326**F**90**/**336**F**90** into the current workpiece feature inspection plan and indication of the distance measurement operation **316**F**90**/**326**F**90**/**336**F**90** in the user interface **305**, is performed, for example, by various components of the CMM workpiece feature inspection operations programming portion **202** and the associated portions and techniques described above in reference to FIG. **2**A.

FIG. **13** is a flow diagram illustrating one exemplary implementation of a routine for programming workpiece feature inspection operations for a CMM, including use of a context sensitive relational command menu according to various exemplary embodiments.

At block **1302**, a CMM user interface **305** is presented to display a 3D view window **320** including at least one of geometric features (**316**F/**326**F/**336**F) of a workpiece **10** to be inspected and inspection operation representations (**316**F/**326**F/**336**F) corresponding to inspection operations to be performed on the geometric features according to a current workpiece feature inspection plan. Each geometric feature (**316**F/**326**F/**336**F) is one of a workpiece feature or a constructed feature that is determined based on at least two workpiece features.

At block **1304**, a context sensitive relational command menu **604** is displayed that indicates a valid set of relational commands including relational feature or relational measurement commands operable to define a corresponding constructed feature or corresponding relational measurement operation to be included in the current workpiece feature inspection plan. The valid set of relational commands is determined based on a concurrently selected geometric feature set including first and second geometric features concurrently selected and indicated in the CMM user interface **305**.

As described and illustrated previously, the concurrently selected first and second geometric features may be displayed in a manner distinguishable from the rest of the workpiece in the 3D view (e.g., highlighted or otherwise marked).

In various exemplary implementations of the routine, the context sensitive relational command menu **604** is not be displayed in the user interface **305** before the first and second relational features are concurrently selected and indicated in the user interface **305**.

While preferred implementations of the present disclosure have been illustrated and described, numerous variations in the illustrated and described arrangements of features and sequences of operations will be apparent to one skilled in the art based on this disclosure. Various alternative forms may be used to implement the principles disclosed herein. In addition, the various implementations described above can be combined to provide further implementations. All of the U.S. patents and U.S. patent applications referred to in this specification are incorporated herein by reference, in their entirety. Aspects of the implementations can be modified, if necessary to employ concepts of the various patents and applications to provide yet further implementations.

The invention claimed is:

1. A system for programming workpiece feature inspection operations for a coordinate measuring machine, the coordinate measuring machine (CMM) including at least one sensor used for determining workpiece feature measurement data, a stage for holding a workpiece wherein at least one of the sensor or the stage are movable relative to one another, and a CMM control portion, the system comprising:

a computer aided design (CAD) file processing portion which inputs or generates a workpiece CAD file corresponding to a workpiece and analyzes the file to automatically determine inspectable workpiece features on the workpiece corresponding to a plurality of geometric feature types;

a geometric relationship analyzer operable to perform geometric analysis operations, including geometric analysis operations usable to analyze relational features that are based on a geometric feature set comprising at least two geometric features, wherein each geometric feature is one of a workpiece feature or a constructed feature that is determined based on at least two workpiece features;

an inspection motion path generation portion that automatically generates at least part of an inspection motion path used in an inspection program generated by the system based on a current workpiece feature inspection plan for inspecting the workpiece represented by the workpiece CAD file; and

a user interface comprising:

an editable plan representation of the current workpiece feature inspection plan for the workpiece corresponding to the CAD file, the editable plan representation comprising at least one of geometric features and inspection operation representations;

a workpiece inspection program simulation portion configured to display a 3D view including at least one of geometric features and inspection operation representations corresponding to inspection opera-

tions to be performed on geometric features according to the current workpiece feature inspection plan; and

a context sensitive menu portion configured to display a context sensitive relational command menu that indicates a valid set of relational commands comprising relational feature or relational measurement commands operable to define a corresponding constructed feature or corresponding relational measurement operation to be included in the current workpiece feature inspection plan, wherein:

the valid set of relational commands is determined based on a concurrently selected geometric feature set comprising at least two geometric features concurrently selected and indicated in the user interface, wherein the at least two geometric features are selected by a user;

the geometric relationship analyzer performs an analysis to determine what relational commands are compatible with the concurrently selected at least two geometric features;

only relational commands that are determined to be compatible with the concurrently selected at least two geometric features are included in the valid set of relational commands;

for a first concurrently selected geometric feature set that comprises at least two geometric features that intersect:

the geometric relationship analyzer determines that an angle measurement command is compatible based on the at least two geometric features intersecting, for which the angle measurement command defines an angle measurement operation to measure an angle between the at least two geometric features that intersect;

the angle measurement command is correspondingly included in a first valid set of relational commands for the first concurrently selected geometric feature set; and

the context sensitive menu portion displays a first context sensitive relational command menu that indicates the first valid set of relational commands for the first concurrently selected geometric feature set; and

for a second concurrently selected geometric feature set that comprises at least two geometric features that are in parallel:

the geometric relationship analyzer determines that a distance measurement command is compatible based on the at least two geometric features being in parallel, for which the distance measurement command defines a distance measurement operation to measure a distance between the at least two geometric features that are in parallel;

the distance measurement command is correspondingly included in a second valid set of relational commands for the second concurrently selected geometric feature set;

the geometric relationship analyzer determines that an angle measurement command is not compatible based on the at least two geometric features being in parallel and is thus invalid and is not included in the second valid set of relational commands for the second concurrently selected geometric feature set; and

the context sensitive menu portion displays a second context sensitive relational command menu that indicates the second valid set of relational commands for the second concurrently selected geometric feature set.

2. The system of claim **1**, wherein each context sensitive relational command menu is configured to indicate the corresponding valid set of relational commands by at least one of: a) limiting the relational commands displayed in the context sensitive relational command menu to the valid set, b) presenting valid and invalid relational commands in different respective formats in the relational command menu, or c) making invalid relational commands inoperable in the relational command menu.

3. The system of claim **1**, wherein each valid set of relational commands is determined and the corresponding context sensitive relational command menu is generated, after the geometric features of the corresponding geometric feature set are concurrently selected and indicated in the user interface.

4. The system of claim **3**, wherein for some concurrently selected geometric feature sets the valid set is empty, and the corresponding context sensitive relational command menu indicates no valid set of relational commands.

5. The system of claim **1**, wherein the workpiece features include one or more of lines, planes, circles, cylinders, spheres and cones, and the constructed features include one or more of a point of intersection, a line of intersection, a circle of intersection, an overlapping plane, an overlapping volume, and a concentric axis.

6. The system of claim **1**, wherein in at least one operating configuration, a complete list of relational commands operable to define a corresponding constructed feature or corresponding relational measurement operation between at least two geometric features is not displayed; and

the corresponding context sensitive relational command menu includes a first subset and excludes a second subset of the relational commands in the complete list wherein the first subset includes the one or more valid relational commands and the second subset excluded from the menu includes one or more invalid relational commands for the corresponding concurrently selected geometric feature set.

7. The system of claim **1**, wherein a valid set of relational commands indicated in a context sensitive relational command menu differs depending on an analysis of the relational features that are based on a corresponding concurrently selected geometric feature set.

8. The system of claim **1**, wherein a valid set of relational commands indicated in a context sensitive relational command menu differs depending on a spatial orientation between the at least two geometric features included in a corresponding concurrently selected geometric feature set.

9. The system of claim **1**, wherein for the first concurrently selected geometric feature set, the first valid set of relational commands further includes an intersection definition command operable to define an intersection between the at least two geometric features that intersect as a constructed feature.

10. The system of claim **1**, wherein in response to selection of a valid relational command from a context sensitive relational command menu, the 3D view is automatically updated to display an indication of the corresponding constructed feature or corresponding relational measurement operation included in the current workpiece feature inspection plan.

11. The system of claim 10, wherein in response to selection of a valid relational command from the context sensitive relational command menu, the editable plan representation is automatically updated to display a representation of the corresponding constructed feature or corresponding relational measurement operation included in the current workpiece feature inspection plan.

12. The system of claim 11, wherein the at least two geometric features of the first concurrently selected geometric feature set are concurrently selected either in the workpiece inspection program simulation portion displaying the 3D view or in the editable plan representation of the current workpiece feature inspection plan.

13. The system of claim 1, wherein:

the user interface further comprises a program view portion that displays the current workpiece feature inspection plan organized as inspection program pseudo-code, actual code, or graphical program operation representations, and

in response to selection of a valid relational command from a context sensitive relational command menu, the program view portion is automatically updated to display the workpiece feature inspection plan that incorporates the corresponding constructed feature or corresponding relational measurement operation.

14. The system of claim 1, wherein the geometric relationship operations of the geometric relationship analyzer comprise operations that analyze the at least two geometric features of the first concurrently selected geometric feature set, to determine a valid set of relational commands corresponding to a set of valid geometric relationships that can be determined between the at least two geometric features of the first concurrently selected geometric feature set.

15. A method for programming workpiece feature inspection operations for a coordinate measuring machine, the coordinate measuring machine (CMM) including at least one sensor used for determining workpiece feature measurement data, a stage for holding a workpiece wherein at least one of the sensor or the stage are movable relative to one another, and a CMM control portion, the method comprising:

providing a computer aided design (CAD) file processing portion which inputs or generates a workpiece CAD file corresponding to a workpiece and analyzes the file to automatically determine inspectable workpiece features on the workpiece corresponding to a plurality of geometric feature types;

providing a geometric relationship analyzer that performs geometric analysis operations, including geometric analysis operations usable to analyze relational features that are based on a geometric feature set comprising at least two geometric features, wherein each geometric feature is one of a workpiece feature or a constructed feature that is determined based on at least two workpiece features;

providing an inspection motion path generation portion that automatically generates at least part of an inspection motion path used in an inspection program generated by the system based on a current workpiece feature inspection plan for inspecting the workpiece represented by the workpiece CAD file; and

providing a user interface comprising:

an editable plan representation of the current workpiece feature inspection plan for the workpiece corresponding to the CAD file, the editable plan representation comprising at least one of geometric features and inspection operation representations;

a workpiece inspection program simulation portion displaying a 3D view including at least one of geometric features and inspection operation representations corresponding to inspection operations to be performed on geometric features according to the current workpiece feature inspection plan; and

a context sensitive menu portion displaying a context sensitive relational command menu that indicates a valid set of relational commands comprising relational feature or relational measurement commands that define a corresponding constructed feature or corresponding relational measurement operation to be included in the current workpiece feature inspection plan, wherein:

the valid set of relational commands is determined based on a concurrently selected geometric feature set comprising at least two geometric features concurrently selected and indicated in the user interface, wherein the at least two geometric features are selected by a user;

the geometric relationship analyzer performs an analysis to determine what relational commands are compatible with the concurrently selected at least two geometric features;

only relational commands that are determined to be compatible with the concurrently selected at least two geometric features are included in the valid set of relational commands;

for a first concurrently selected geometric feature set that comprises at least two geometric features that intersect:

the geometric relationship analyzer determines that an angle measurement command is compatible based on the at least two geometric features intersecting, for which the angle measurement command defines an angle measurement operation to measure an angle between the at least two geometric features that intersect;

the angle measurement command is correspondingly included in a first valid set of relational commands for the first concurrently selected geometric feature set; and

the context sensitive menu portion displays a first context sensitive relational command menu that indicates the first valid set of relational commands for the first concurrently selected geometric feature set; and

for a second concurrently selected geometric feature set that comprises at least two geometric features that are in parallel:

the geometric relationship analyzer determines that a distance measurement command is compatible based on the at least two geometric features being in parallel, for which the distance measurement command defines a distance measurement operation to measure a distance between the at least two geometric features that are in parallel;

the distance measurement command is correspondingly included in a second valid set of relational commands for the second concurrently selected geometric feature set;

the geometric relationship analyzer determines that an angle measurement command is not compatible based on the at least two geometric features being in parallel and is thus invalid and is not included in the second valid set of rela-

tional commands for the second concurrently selected geometric feature set; and

the context sensitive menu portion displays a second context sensitive relational command menu that indicates the second valid set of relational commands for the second concurrently selected geometric feature set.

16. The method of claim **15**, wherein each context sensitive relational command menu indicates the corresponding valid set of relational commands by at least one of: a) limiting the relational commands displayed in the context sensitive relational command menu to the valid set, b) presenting valid and invalid relational commands in different respective formats in the relational command menu, or c) making invalid relational commands inoperable in the relational command menu.

17. The method of claim **15**, wherein each valid set of relational commands is determined and the corresponding context sensitive relational command menu is generated, after the geometric features of the corresponding geometric feature set are concurrently selected and indicated in the user interface.

18. The method of claim **15**, wherein the workpiece features include one or more of lines, planes, circles, cylinders, spheres and cones, and the constructed features include one or more of a point of intersection, a line of intersection, a circle of intersection, an overlapping plane, an overlapping volume, and a concentric axis.

19. The method of claim **15**, wherein in at least one operating configuration, a complete list of relational commands operable to define a corresponding constructed feature or corresponding relational measurement operation between at least two geometric features is not displayed; and

the corresponding context sensitive relational command menu includes a first subset and excludes a second subset of the relational commands in the complete list wherein the first subset includes the one or more valid relational commands and the second subset excluded from the menu includes one or more invalid relational commands for the corresponding concurrently selected geometric feature set.

20. The method of claim **15**, wherein a valid set of relational commands indicated in a context sensitive relational command menu differs depending on at least one of:

an analysis of the relational features that are based on a corresponding concurrently selected geometric feature set; or

a spatial orientation between the at least two geometric features included in a corresponding concurrently selected geometric feature set.

21. The method of claim **15**, wherein for the first concurrently selected geometric feature set:

the geometric relationship analyzer further determines that an intersection definition command is compatible based on the at least two geometric features intersecting, for which the intersection definition command defines an intersection between the at least two geometric features as a constructed feature; and

the intersection definition command is correspondingly included as a relational feature command in the first valid set of relational commands for the first concurrently selected geometric feature set.

22. The method of claim **15**, wherein:

in response to selection of a valid relational command from a context sensitive relational command menu, the 3D view is automatically updated to display an indication of the corresponding constructed feature or corresponding relational measurement operation included in the current workpiece feature inspection plan; and

in response to selection of a valid relational command from the context sensitive relational command menu, the editable plan representation is automatically updated to display a representation of the corresponding constructed feature or corresponding relational measurement operation included in the current workpiece feature inspection plan.

23. The method of claim **15**, wherein:

the user interface further comprises a program view portion that displays the current workpiece feature inspection plan organized as inspection program pseudo-code, actual code, or graphical program operation representations; and

in response to selection of a valid relational command from a context sensitive relational command menu, the program view portion is automatically updated to display the workpiece feature inspection plan that incorporates the corresponding constructed feature or corresponding relational measurement operation.

24. The method of claim **15**, wherein the at least two geometric features of the first concurrently selected geometric feature set are concurrently selected either in the workpiece inspection program simulation portion displaying the 3D view or in the editable plan representation of the current workpiece feature inspection plan.

25. The method of claim **15**, wherein the geometric relationship operations of the geometric relationship analyzer comprise operations that analyze the at least two geometric features of the first concurrently selected geometric feature set, to determine a valid set of relational commands corresponding to a set of valid geometric relationships that can be determined between the at least two geometric features of the first concurrently selected geometric feature set.

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